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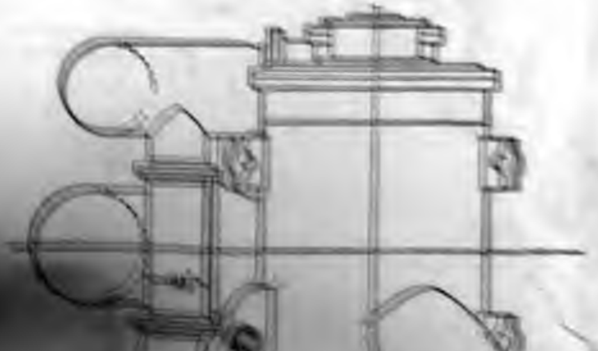

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Ex-President of the Electrical Section of the Franklin Institute.

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REFACE TO THE FIFTEENTH EDITION.

e success of Roper's "Engineer's Handy Book" is a suf-
proof that its general plan and scope are well adapted
e needs of those for whom it was written. In rewriting
ok, therefore, the Editors have been largely guided by
r editions. They have, however, endeavored to secure a
logical arrangement of the subject-matter, to eliminate ir-
nt material, to avoid unnecessary duplications occurring in
or descriptions of machines of the same type, to replace
ated or obsolete matter with that which is new, and finally
a great deal which the advance in engineering in the past
ars has rendered necessary.

he sections covering the "Steam Boiler and Engine" and
pliances used in connection with them, many descriptions
olete types have been dropped and modern types substi-
In this connection they have endeavored to describe
ail at least one piece of machinery of each important
adding others of the same type only where the design
ned important variations. In using any particular make
aratus to represent a type they do not intend to indicate
reference for that make nor to imply that it is better than
of the same type. The *selections* are made because more

nearly representing the particular type to which they belong because the available data and cuts were best suited for the poses of illustration.

The subjects, "Materials and Their Strength," and "Po Its Transmission and Measurement," have been treated much m fully than in the original edition, and extensive tables on power required to drive machine tools have been added. M of the data contained in these tables is based on the result measurements made by the Editors at the Baldwin Locomo Works, Philadelphia.

In the section on "Electricity" the fundamental experim on which electrical apparatus depends have been described the methods of measuring the common electrical quantities gi The principles of the dynamo and battery and the method electrical distribution, as well as the apparatus in which electr energy is used, have all been treated in a general way.

The Editors have found that many of the brightest statio engineers unfortunately do not have clear ideas of *force*, w *power*, and other fundamental mechanical units, and the f chapter has been devoted to those units and their relation to e other. It is strongly urged that all stationary engineers who not familiar with the principles of mechanics should caref study this chapter. Many are likewise unable to use sim formulæ, and are therefore compelled to employ complex r for their calculations. The knowledge necessary for their us so easy to acquire and the resulting advantage so great, that users of this work are urged most strongly to study the ma pertaining to them in the last chapter of this book. In m cases both rules and formulæ for calculations are given, with *amples* illustrating their use.

ho have problems involving tedious arithmetical operald familiarize themselves with the use of logarithms.
lusion, the Editors take this opportunity of acknowleir indebtedness to Messrs. Paul A. N. Winand and A.
ıg, of the Otto Gas Engine Works, for their aid in pree chapter on "Gas and Gasoline Engines," and to the
who have aided in the revision by the use of valuable
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Iron Works Co., Pelton Water Wheel Co., J. A.
s Sons Co., and the various technical journals and trade
of apparatus referred to in the text.

nications from readers calling attention to errors and which may be discovered in using the book will be
d by the Editors.

Edwin R. Keller,
Clayton W. Pike.

LPHIA, Pa., February, 1899.

PREFACE TO THE FIRST EDITION.

s quite customary for persons to write books on the steam-en- ne, and then offer as an apology for so doing, that they have vered that there is no practical treatise on the same subject in arket, which shows either a lack of modesty on their part, and nt of appreciation of what has already been written, or an un- gness to do justice to those who have previously treated the subject. There is no want of literature on the steam-engine; ct, it would be difficult for the most experienced engineer or ted author to add anything original. The steam-engine of the nt day is probably as perfect as it ever will be; in fact, there ot been any important improvement made in any class of -engines for several years, except in the quality of the mate- employed in their construction and refinement of workman consequently, the work of those who treat on the steam- e, for the present, must be confined simply to abbreviating, ifying, correcting, and explaining what has already been writ- s well as noting the results of the experiments which are tried t the efficiency of different designs of steam-engines. Who- will apply himself to this object in the future, will be per- ng what has long been needed. Of course, we may discover engine that will be radically different from any in use at the nt day, which would involve the necessity of a new order of ture and new theories, but such an innovation is highly im- ble, and casts only a dim shadow in the future.

is book was not written for the purpose of instructing engi- how to design or proportion steam-engines or boilers, but rather form them how *to take care of* and manage them intelligently, as well as to furnish to those intending to qualify themselves United States Navy, Revenue Service, Mercantile Marine, take charge of the better class of stationary steam-engines, plain, practical treatise. In order to enhance its value to engineers, as well as those of limited education, none but the p language has been used. This has not been done for the pur encouraging the engineer to dispense with the use of mathe or discard theories, as all our great triumphs in mechanical s have been based on theories and demonstrated by practice.

In the discussion of the different subjects brevity has be hered to, because the spirit of the age demands it, even in th cussion of the most important subjects. There can be no why the reader should be compelled to wade through chapt matter to obtain information which may be condensed into terse and intelligent paragraphs, nor to deal with the dea when the living present is before him. The mathematical fo employed have been abbreviated, since it is immaterial how a lem is worked, providing the result is correct and suscept easy explanation. Up to the present time, the knowledge to gently apply the steam-engine indicator has been confined to persons in every country styling themselves experts. This arose from the fact that authors who have heretofore trea this subject were men of literary ability and well versed in matics, who found it more agreeable to elucidate their sub their own peculiar style than in any other.

The writer's experience of over thirty-five years, and hi ciation with all classes of engineers, enable him to understan the kind of information most needed by the average engineer. sequently, he has undertaken the task of furnishing it, and ho he has succeeded in the accomplishment of his object, he che leaves to the reader to decide. If it should appear that he h ceeded in imparting useful and important information to the bers of a profession to which he himself belongs, he will feel warded for his efforts.

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THE ENGINEER'S HANDY-BOOK.

PART I.

POWER, TRANSMISSION, AND MEASUREMENT.

CHAPTER I.

MECHANICS.

All machinery, when analyzed, will be found to consist of a combination of six simple machines, commonly called *mechanical elements.* The six elements are respectively the *lever*, the *pulley*, the *wheel and axle*, the *inclined plane*, the *wedge*, and the *screw.* Though they are not powers, or, in other words, sources of power or force, yet they transmit and diffuse or concentrate forces. The essential idea of machinery is that it renders force available for effecting practical ends. Machines prepare, as it were, the raw material of force supplied to us from natural sources. It is transmitted and modified by certain combinations of the elements of machinery, and is given off, at last, in a condition suitable for producing the desired mechanical effect. We do not create force; the object of machinery is to transmit it, and diffuse or concentrate it in one or more points of action. The various diffused or concentrated forces, then, being added together, will amount exactly to the original available force.

Machines.—Machines are instruments employed to regulate motion, so as to save either time or force. The maximum effect of machines *is the greatest effect* which can be produced by them. *In all machines that work* with a uniform motion there are a certain velocity and a certain load of resistance that yield greatest effect, and which are therefore more advantageous th any other. A machine may be so heavily charged that the tion resulting from the application of any given power will but just sufficient to overcome it, and, if any motion ensue, will be very trifling, and the whole effect will be very slight. the machine is very lightly loaded, it may give great velocity the load; but, from the smallness of its quantity, the effect m still be very inconsiderable; consequently, between these t loads, there must be some intermediate one that will render t effect the greatest possible. This is equally true in the appli tion of animal strength, as in machines.

Mechanics.— Mechanics is that branch of natural philosop which treats of three simple physical elements, force, motion, a time, with their combinations, constituting power, space, a work. Mechanics, regarded as a science, comprehends the of our knowledge relative to the sensible motions of bodies eith actually existing, or expressed by the opposition of forces te ing to produce motion. The science is thus resolvable into a co of discovered laws, applying to the causes which occasion a modify the direction and the velocities of motion, and is the fore distinct from those branches of science, in which, althou presenting phenomena of motion in sensible portions of matt we do not consider the circumstances and laws of these motio but only the effects produced.

When motion itself is considered, the reasoning belongs mechanics, and it is probable that, as our knowledge of the la which govern the phenomena that are evolved under the hand the experimental philosopher becomes more extended, a wid meaning will be given to the science of motion. The definiti which is here given of mechanics is not coeval with the nam The science, like most other sciences, has gradually expanded its present extent. It was originally the science of machine *these being the first* subjects of its speculation; and, as eve *material combination* employed for producing or preventing tion may be regarded as a machine, and may be resolved into the same elementary principles as those employed in machines,—the mechanical powers,—the name "mechanics" came to be applied to motion, and the tendency to motion of any bodies whatever. Mechanics still continues to be defined by some the "science of force," and there does not appear to be any valid objection to the definition. Force is the cause of motion, and its laws are identical with the laws of motion; and, consequently, the science of force coincides, in all its parts, with the science of motion, which is mechanics.

Force.—Force is the cause of motion or change of motion in material bodies. Every change of motion, viz., every change in the velocity of a body, must be regarded as the effect of a force. On the other hand, rest, or the invariability of the state of motion of a body, must not be attributed to the absence of forces, since opposite forces destroy each other and produce no effect. The force of gravity with which a body falls to the ground, still acts, though the body rests; but this action is counteracted by the solidity of the material upon which it reposes. Forces that are balanced so as to produce rest, are called statical forces or pressures, to distinguish them from moving, deflecting, accelerating, or retarding forces, *i. e.*, such as are producing motion, or a change in the direction or velocity of motion. This distinction is wholly artificial, as the same force may act in any of these modes; it may sometimes be a statical and sometimes an accelerating force.

Force is any action which can be expressed simply by weight, and is distinguished by a great variety of terms, such as attraction, repulsion, gravity, pressure, tension, compression, cohesion, adhesion, resistance, inertia, strain, stress, strength, thrust, burden, load, squeeze, pull, push, pinch, punch, etc., all of which may be measured or expressed by weight without regard to motion, time, power, or work.

Forces are either external or *internal* (molecular). External forces are *those which one body exerts* on another body. Molecular *forces are those exerted by the* particles of a body on neig boring particles. Such molecular forces may be either attrac or repellant, or both. In most cases both forces are acting. the attractive forces preponderate, the body will be in a s state; if the forces are equal, in a liquid state; while if the re lant forces are stronger than the attractive, the body will be the gaseous condition.

The Unit of Force employed by American and English e neers is the pound avoirdupois.

Inertia is that property of matter by virtue of which it re any attempt to change its condition. Thus if a body is at res force must be applied in order to set it in motion. If it is in tion, a force must be applied to bring it to rest. The heavier body the greater the force necessary to overcome its inertia.

Motion.—Motion, in mechanics, is a change of place, or i that property inherent in matter by which it passes from point of space to another. Absolute motion is the absol change of place in a moving body, independent of any ot motion whatever; in which general sense, however, it never f under our observation. All those motions, which we conside absolute, are in fact only relative, being referred to the ea which is itself in motion. By absolute motion, therefore, must only understand that which is so with regard to some fi point upon the earth, this being the sense in which it is interpre by writers on this subject. Accelerated motion is that whic continually receiving constant accessions of velocity. Ang motion is the motion of a body as referred to a centre, ab which it revolves. Compound motion is that which is produ by two or more powers acting in different directions. Natu motion is that which is natural to bodies, or that which ar from the action of gravity. Parallel Motions.—Contriva of this kind are required for the conversion of rotary and al nating angular motion into rectilineal motion, and the conver *but* the absolute necessity there is of guiding the path of a pis *in a steam-engine,* has called forth more attention to the princip *and mechanism* of parallel motions than would otherwise, ility, have been awarded to the subject. Relative motion relative change of place in one or more moving bodies. led motion is that which suffers continual diminution of y, the laws of which are the reverse of those of accelerated . Rotary motion, turning as a wheel on its axis, pertain- or resembling the motion of a wheel. Rotary motions avorite ones with ancient philosophers. They considered a as the most perfect of all figures, and erroneously concluded body in motion would naturally revolve in one.

the substitution of circular for straight motions, and of uous for alternating ones, may be attributed nearly all the niences and elegancies of civilized life. It is not too much rt, that the present advanced state of science and the arts to revolving mechanism. From the earliest times it had an object to convert, whenever practicable, the rectilinear ciprocating movements of machines into circular and con- s ones. Old mechanics seem to have been led to this result t tact or natural sagacity, that is more or less common to nes and people. Thus the dragging of heavy loads on the d led to the adoption of wheels and rollers,— hence carts rriages. The rotary movements of the drill superseded the ating one of the punch and gouge, in making perforations; hetstone gave way to the revolving grindstone; the turning- produced round forms infinitely more accurate and more ex- ously than the uncertain and irregular carving or cutting the knife.

s of Motion.—Newton's:

A body at rest will remain at rest, or if in motion will continue to move uniformly in a straight line till acted upon by some force.

If a body be acted upon by several forces, it will obey each as if the others did not exist, and this whether the body be at rest or in motion.

If a force *act to change the state* of a body with respect to *rest or motion, the body* will offer a resistance equal to and directly opposed to the force. Or to every actio there is opposed an equal and opposite reaction.

Perpetual Motion.—In mechanics, a machine which, when se in motion, would continue to move forever, or, at least, until destroyed by the friction of its parts, without the aid of any exterio cause, would constitute perpetual motion. The discovery o perpetual motion has always been a celebrated problem in mechanics, on which many ingenious, though in general ill-instructed persons have spent their time; but all the labor bestowed on i has proved abortive. In fact, the impossibility of its existenc has been fully demonstrated from the known laws of matter. In speaking of perpetual motion, it is to be understood that, fro among the forces by which motion may be produced, we are t exclude not only air and water, but other natural agents, as hea atmospheric changes, etc. The only admissible agents are th inertia of matter, and its attractive forces, which may all be considered of the same kind as gravitation. It is an admitted principle in philosophy, that action and reaction are equal, and tha when motion is communicated from one body to another, the fir loses just as much as is gained by the second. But every movi body is continually retarded by two passive forces,—the resi ance of the air and friction. In order, therefore, that motio may be continued without diminution, one of two things is nece sary—either that it be maintained by an exterior force, (in whi case it would cease to be what we understand by a perpetual m tion,) or that the resistance of the air and friction be annihilated which is practically impossible.

The motion cannot be perpetuated, till these retarding forc are compensated, and they can only be compensated by an exteri force, as the force, communicated to any body, cannot be greate than the generating force, which is only sufficient to continue th same quantity of motion, when there is no resistance. The erro of confounding mere pressure with energy available to produ *power, is the main* origin of the majority of attempts at perpetu *motion, and even* sometimes causes, among confused minds, e ated expectations about the effects to be obtained from me- ical contrivances. A wound-up spring is exactly equivalent weight. It may exert a certain pressure, great in proportion size and strength; but, unless it is allowed to unwind it, it ot produce motion or power. It is the same with compressed r gases; they are, in fact, nothing but wound-up springs, with lifference, however, that, in place of needing mechanical power ind them up, we may use either heat, chemical agencies, or ricity.

elocity or Speed is the rate of motion—that is, the space elled over by a moving body divided by the time required. s, if a railroad train requires two hours to cover the distance inety miles between Philadelphia and New York, its velocity nety divided by two, or 45 miles per hour. The same veloc- night be otherwise expressed as three-quarters of a mile per ute, or 240 rods per minute, or 4 rods per second, or 66 feet second.

elocity is uniform if equal spaces are passed over in equal times.

cceleration is the rate at which velocity changes, or it is the n or loss in velocity in one second. For instance, a falling y in the first second passes over 16.1 feet, in the next second 3 feet, and so on. Its average velocity in the first second is 1 feet per second, and in the next second is 48.3 feet per ond; the gain in velocity is 32.2 feet each second, and therefore say the body has an acceleration of 32.2 feet per second.

Falling Bodies are subject to two forces, that of gravitation d that of the resistance of the air. The latter is for ordinary apes so small as to be neglected, and the relations existing are vered by the following simple formulæ:

Let v = velocity of falling body expressed in feet per second.

g = acceleration due to gravity, found by measurement to be about 32.2 feet.

t = time in seconds, reckoned from moment of starting to fall.

h = *distance passed* over in t seconds.

Then $g=\frac{v}{t}$ by definition.

Also $v=$ square root of $2\times g\times h=\sqrt{64.4\,h}$ by experin

and $h=\frac{g\times t\times t}{2}=\frac{gt^2}{2}$ by experiment.

The following examples will show how these formu applied:

1st. If a body starts from rest and falls freely, what wil velocity at the end of the fifth second?

Taking $g=\frac{v}{t}$ and substituting the actual values of g an have $32.2=\frac{v}{5}$, or $v=5\times 32.2=161$, or velocity at end c second is 161 feet per second.

2d. If a body starts to fall freely from a height of 50 fee will be its velocity when it reaches the earth?

Taking the formula $v=\sqrt{64.4\,h}$ and substituting for h it 50 feet, we have $v=\sqrt{64.4\times 50}=\sqrt{3220}$. Looking in th of squares we find that the square root of 3220 is betwee and 56.8, and nearer to 56.8. The velocity when it reache will be 56.8 feet per second.

3d. If a body be allowed to fall, what distance will i passed through at the end of the tenth second?

Taking $h=\frac{gt^2}{2}$ and substituting, we have $h=\frac{32.2\times 10\times}{2}$ reducing, $h=\frac{3220}{2}=1610$ feet.

The following table is convenient for use in such problen

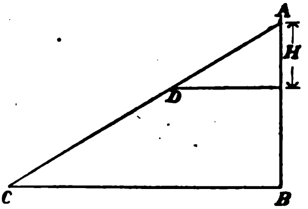
t=seconds	1st	2d	3d	4th	5th	6th	7th	8th
v=velocity at end of t seconds=$32.2\times$	1	2	3	4	5	6	7	8
s=distance travelled in each sec.=$\frac{32.2}{2}\times$	1	3	5	7	9	11	13	15
h=total distance in t seconds=$\frac{32.2}{2}\times$	1	4	9	16	25	36	49	64

Thus the velocity at the end of the fifth second is $32.2\times$ *feet per second.* The distance passed over in the sixth se

$\frac{\times 11}{2} = 177.1$ feet. The total distance passed over in four nds is $\frac{32.2\times 16}{2} = 257.6$ feet, and in ten seconds is $\frac{32.2\times 100}{2}$ 10 feet.

lotion Down an Inclined Plane.—Neglecting friction, the eding formulæ may be used for the motion of bodies down ined planes. In this case H is the vertical height through ch the body descends. The distance D measured down the e may be found by proportion.

xample.—Suppose a hill, whose vertical height $A\,B = 1000$, is covered with snow and a oth icy crust is formed, as is uently the case in New Engl. The distance $A\,C$ is known e 2000 feet. A sled starts at nd descends. Friction neged, the preceding table gives H = vertical height = at end first second 16.2 feet, second nd = 64.4 feet, third second = 144.9 feet, fourth second = 257.6 . At the end of the fourth second the distance $A\,D$ is the e fraction of $A\,C$ as 257.6 is of 1000. Therefore at end of the rth second the sled will have travelled along $A\,C$ a distance $= 2000 \times \frac{257.6}{1000} = 515.2$ feet. The velocity in the direction at the end of the fourth second is, from the table, 32.2 × 4 28.8 feet per second. As the sled has moved in 4 seconds .2 feet along $A\,C$ while descending vertically 257.6 feet, the ocity along $A\,C$ at the end of the fourth second will be $\frac{515.2}{257.6}$ e velocity in the direction of $A\,B$. In fact, at any instant velocity along $A\,C$ will be $\frac{515.2}{257.6}$ times as great as the veloc-



ity in the direction $A\,B$. Notice that $\frac{515.2}{257.6} = 2$, and that the $\frac{\text{distance } A\,C}{\text{distance } A\,B} = 2$ also. In general, the velocity along $A\,C =$ velocity along $A\,B \times \frac{\text{distance } A\,C}{\text{distance } A\,B}$.

Mass.—The mass of a body is defined to be its weight in pounds divided by the value of g at the place where it is weighed. This value of g, the acceleration imparted by gravity to a falling body, differs somewhat in value at different places on the earth's surface owing to the fact that the earth is not a perfect sphere. As we go up a mountain g diminishes, because we are getting farther away from the earth and its pull on a body is less. The weight of a body measured by a spring balance also diminishes as we go away from the earth's centre in just the same proportion as the value of g. Therefore the quotient of weight $\div g$ is a constant, and it is this quotient which we agree to call the mass of a body.

Relation between Mass, Force, and Acceleration.—If a force of F pounds be applied to a mass M, the mass will be put in motion and will be given an acceleration of a feet per second. That is, in the form of the usual equation $F = M\,a$. If we know any two of these three quantities, we can by simple arithmetic find the third. For example, What force must be applied to a certain body at rest to give it in one second a velocity of 20 feet per second. Recollecting that acceleration is the change in velocity in one second, the value of a is 20. Weigh the body, and sup-
we find its weight to be 64.4 pounds. Its mass M is then
$\frac{\text{ounds}}{} = \frac{64.4}{32.2} = 2$. Substituting in the formula, we have
nds, the necessary force.

Suppose a cart weighing 100 pounds
20 feet per second by a man on a
is attached to the cycle throug
balance will read a cer

amount, and this reading gives the force in pounds necessary to overcome the friction of the cart, and the resistance of the air. Suppose it to be 10 pounds. Now suppose the cyclist speeds up, increasing his velocity to 22 feet per second. There is a gain of velocity or an acceleration of 2 feet per second. To produce this acceleration there must be an additional force exerted by the cyclist, and this increase will be shown on the balance, whose reading will be increased. The increase will be due to two causes: 1st, the extra pounds pull needed to overcome the increased air resistance at the higher speed, which will be somewhere near 2 pounds; 2d, the force needed to accelerate the cart 2 feet per second. This force is $F = Ma = \frac{100 \times 2}{32.2}$, or 6.2 pounds. So that during the second in which the speed is being raised the balance will read about 18 pounds. If after reaching the speed of 22 feet per second, the cyclist continues at that speed, the reading of the balance will drop to about 12 pounds.

If now the cyclist slows up, changing in one second from a speed of 22 to 20 feet per second, the reverse action will take place, and during this second the balance-reading will drop from 12 by an amount, 6.2 pounds, which is needed to retard the cart and by 2 pounds more, which is the difference in full between what is necessary to maintain the cart at 22 feet and that needed to keep it at 20 feet per second.

The Momentum of a body is defined as the product of its mass times its velocity. For instance, a body weighing 100 pounds and moving 50 feet per second has a momentum of $\frac{\text{weight} \times \text{velocity}}{g}$, or $\frac{100 \times 50}{32.2} = 155.28$.

It is equal in numbers to the force which will start the body from rest and accelerate it till at the end of one second it has the given velocity. Thus, suppose a force of 155.28 pounds be applied to a weight of 100 pounds, what velocity will it have at the end of the first *second?*

$$F = Ma = \frac{\text{weight} \times \text{acceleration}}{g}.$$

$$155.28 = \frac{100 \times a}{32.2}, \quad \text{or} \quad a = \frac{155.28 \times 32.2}{100} = 50 \text{ feet per second}$$

If the acceleration is 50 feet per second, since by definition t acceleration is the gain in velocity in one second, the velocity the body one second after the application of the force of 155. pounds must be 50 feet per second. It is also evident that 155.28 pounds will in one second impart to a body previously rest a velocity of 50 feet per second, it will also bring to rest one second a body weighing 100 pounds which is moving at velocity of 50 feet per second. The momentum of a moving bo is therefore equal to the force which must be used to bring it rest in one second.

Energy or Work in mechanics involves two things—force a space. If only one be present, no work is done. For instan a weight resting on a table is doing no work, for while it exerts pressure or force on the table it does not move. If it be allow to fall, say, for example, being attached to a cord passing over drum, it can be made to do work.

The unit of work among American and English engineers the foot-pound—*i. e.*, the work done in raising one pound throu a distance of one foot. The same work would be done in raisi 2 pounds to a height of 6 inches or 12 pounds to a height of inch. The number of foot-pounds of work done is, then, alwa equal to the force in pounds multiplied by the distance in fe over which it is exerted. For example, a man lifts 100 poun to a table 4 feet high. He does 400 foot-pounds of work. I may lift it slowly or quickly—it makes no difference in t amount of work done. He may lift it up one foot and place on a block, rest a while, then raise on to another block two fe high, and so on. The number of foot-pounds of work perform by him remains the same.

The work which the man has done is stored up in the 1 *pound weight, and* will remain there till the weight is allowed ll. If the weight be allowed to fall one foot, it can be made to › 100×1, or 100 foot-pounds of useful work, if, as suggested ove, we attach it to a rope passing over a drum, or it can be lowed to fall suddenly a distance of one foot and give up its ored energy in the form of heat, which heat may or may not be efully employed. If allowed to fall another foot, it gives up other 100 foot-pounds, and so on till it reaches its original vel, when it will have given up the 400 foot-pounds stored in by virtue of its having been raised four feet. The case of a wer clock is an excellent example of the storing the work of man by a raised weight and afterward employing it usefully y letting the weight fall slowly. A similar storage of work curs in winding a watch or spring clock. In the case of a eam engine taking steam the entire stroke, exhausting into a acuum and with a pressure of 100 pounds to the square inch, iameter 8 inches, length of stroke 10 inches, the number of foot-ounds work done on the forward stroke is

$$00 \times \text{area of piston} \times \frac{10}{12} = \frac{100 \times 25.1328 \times 10}{12} = 2094.4 \text{ foot-pounds.}$$

Energy, strictly speaking, is stored work, or the capacity for loing work. The word is often employed in the place of work. Energy existing in a body at rest is called *potential* energy. Such s a raised weight, a coiled spring, or water pumped to a height. The number of foot-pounds stored up is equal to the number of ounds raised multiplied by the height. Energy existing in a noving body is called *kinetic*. The number of foot-pounds stored n a body of weight W and velocity V is equal to the work done in starting it from rest and accelerating it till its velocity is V, and this number of foot-pounds is $\frac{1}{2} M V^2$ or $\frac{W V^2}{g \times 2}$. Thus a cannon-ball weighing 10 pounds and moving 1000 feet per second has $\frac{10 \times 1000 \times 1000}{32.2 \times 2}$ or 153726 foot-pounds of energy stored up in it. *The explosion of the powder* produced this energy. When *he cannon-ball strikes it gives this* amount up in the form of hea less, of course, that which has been lost in overcoming the friction of the air.

Forms of Energy:

Potential.—Stresses—either compression, extension, or torsion.
Gravitational, between two separated bodies.
Chemical, between two separated atoms.
Electrical, between two separated charged bodies.
Magnetic, between two separated magnetized bodies.

Kinetic.—Rectilinear or rotary motion.
Vibration, such as sound.
Wave-motions, such as light.
Heat—molecular motion.
Electric current flow.

Source of Energy.—The rays of the sun are the primary source of all energy which man employs. They cause the growth of plants, which furnish food and fuel to man. Our vast coal deposits, which now are drawn on to furnish most of the world's power, are only the energy of the sun's rays stored up in plants in bygone ages. It is the sun which now raises water from the sea-level to the mountain-top, thus giving it potential energy which is used to turn water-wheels and made to do useful work.

Conservation of Energy.—The amount of energy in the universe cannot be changed by man. He can transmit it or change the form in which it appears, but he can in no wise create it or destroy it. A bushel of coal has a certain number of foot-pounds of energy stored in it. This energy is chemical in form, consisting in the attraction which the oxygen of the air has for the carbon of the coal. If the coal is burned, an exactly equal number of foot-pounds is liberated in the form of heat. If burned in a boiler, the potential chemical energy of the coal is changed into kinetic energy of heat; this is used in raising the temperature and pressure of steam, and the confined steam has an equal number of foot-pounds less what escaped as heat up the boiler-stack. The steam taken into the engine is allowed to expand, and gives up a part of its potential energy to the piston, the rest escapi is heat into the exhaust. The energy of the piston is made to turn the crankshaft, and this may again give up its energy (except that lost as heat in friction in the engine) to a dynamo, which changes the rotary mechanical energy into electric energy (less some lost as heat). This electrical energy may be transmitted over wires and run into motors, changing electrical into mechanical energy again, or into lamps, changing from electrical to light and heat energy, or may even be run into a chemical solution, and by decomposing this into its elements, change the electrical energy into the original form of chemical energy. The sum of this chemical energy plus that wasted in heat at the different transformations will exactly equal the energy originally in the bushel of coal. Nothing can be done by any combination of machines or processes to increase the energy in the coal. All that can be done is to make the desired transformations as efficient as possible, wasting as little as possible in the form of heat. This is by no means easy, for all forms of energy tend to assume the form of heat, and in the chain of transformations mentioned above not one-twentieth of the energy in the coal would be found in the form of chemical energy at the end, the remainder having been changed into the form of heat at different stages of the process.

Power is the rate at which work is done. If a man lifts 100 pounds 4 feet twice per minute, or 120 times per hour, his rate of working is 4 × 100 × 120, or 48,000 foot-pounds per hour.

Horse-Power.—James Watt, experimenting on the ability of draught horses to do work for a short time, found that they could do work at the rate of about 550 foot-pounds per second, or 33,000 foot-pounds per minute, and this rate is adopted as the horse-power. The man above would be doing work at the rate of $\frac{48,000}{33,000}$, or 1.4555 + horse-power.

'The power is equal to work divided by time. Thus if a man does *55 pounds 100 times in 15 minutes*, he does $\frac{5500}{15}$ foot-pound per minute, or $\frac{5500}{15 \times 60}$ foot-pounds per second. 1 horse-pow being 550 foot-pounds per second, the power in horse-power $\frac{5500}{15 \times 60 \times 550} = \frac{1}{90}$ horse-power.

To obtain the work done, multiply the force in pounds by the ι*tance in feet.*

*To obtain the power, divide this product by the time in min*ι *required to do the work.*

To obtain the horse-power, divide again by 33,000.

Example.—A steam engine is supplied with steam at 1 pounds pressure, a vacuum being maintained on the other side the piston. It makes 240 revolutions per minute. The diame of piston is 10 inches and stroke 12 inches, what is its ho power, steam being carried through to end of stroke? We h the following solution:

Velocity = distance divided by time occupied in going over tl distance.

Work = force in pounds × distance in feet.

Power = work divided by time or $\frac{\text{force} \times \text{distance}}{\text{time}} = \text{force} \times \text{veloci}$

Force = 100 × area = 100 × 78.54 = 7854 pounds.

Distance per stroke = 1 foot.

Distance per revolution = 2 feet.

Distance per minute = 480 feet = velocity per minute.

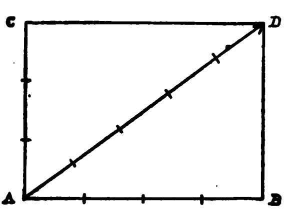
Power = force × velocity = 7854 × 480 foot-pounds per minute.

Horse-power $= \frac{7854 \times 480}{33{,}000} = 114.24.$

In this calculation no allowance has been made for the dim ished area of one side of the piston owing to the piston-rod.

Graphic Representation of Forces.—The three qualities of force are—its direction, intensity, and point of application. Th are represented graphically by a straight line whose direction the same as that of the force, whose length is proportional to intensity of the force, and one of whose ends represents the po

on. This method of representation is extremely im-
n several forces are acting on one body, for by it we
easily calculate what is the net or resultant force act-
gth, and direction.



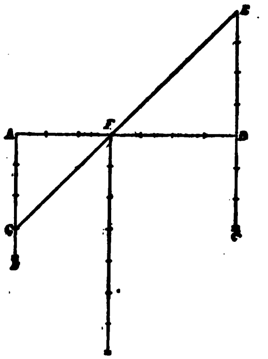
ram of Forces.—Let two forces of 4 and 3 pounds
nt *A* at an angle of, say, 90° with each other. Draw
four units long and par-
direction of the force 4.
three units long parallel
3. Then *A B* represents
n, intensity, and point of
of one force, and *A C* rep-
arly the other force. Com-
rallelogram *A B D C* by
D parallel to *A C* and *C D* parallel to *A B*. Then
present a force which, if applied to a body at *A*, will
me effect upon the body as would have the two forces
ounds. In this particular case the resultant force will
nsity of 5 pounds, and will make an angle of 36° 53′
ection *A B*. If more than two bodies are acting, we
r resultant by taking two of them and obtaining their
above, and then combining this resultant with the
in the same manner.

es in the same line have a resultant equal to their
act in the same direction, and a resultant equal to
nce if they act in opposite directions. When two
ces are equal and opposite, the body on which they
(if they are acting in the same line). Thus a stone
spring-balance has acting downward a force equal to
ue to gravity. A precisely equal and opposite force,
retched spring, acts upward. The resultant of these
ro, the stone is at rest.

orces.—When two or more forces act in the same
d in parallel lines their resultant intensity is equal
. Its direction is parallel to all the forces. The

point of application of the resultant force may be fou follows:

Let *A B* and *CD* represent the two parallel forces of 3 pounds respectively. Continue *C D* to *E*, making di *D E* = *A B*, make *A G* equal to *CD* and draw *E G*. Ther the point of application of the resultant of the two forces



the value of this resultant would be 7 pounds. The distance is to *FD* as 3 is to 4. A force of 7 pounds upward applied would just balance the two forces *A B* and *C D*.

Moment, or Statical Moment.—In order to handle easil subject of levers and tendency to rotation it is best to treat by means of moments so called. The moment of a force ab point is equal to the intensity of the force in pounds mult by the length of the line drawn perpendicularly from the po the line of direction of the force. Thus in the figure the mo of the force *A B* about the point *F* is 4 × 3 = 12, and the mo of the force *C D* about the point *F* is 3 × 4 = 12.

If a rod *A D* having a weight of 4 pounds at *A* and 3 p at *B* were supported on a knife-edge at *F*, it would just ba *The downward force* of 7 pounds acting at F is just balanc *the upward reaction* of the knife-edge.

If weight were added at A, the end A would tip down, the rod ending to rotate about F as a centre. Notice that the moment f the force $A\,B$ is now greater than that of $C\,D$. Whenever he moments of two forces about a point are equal and the forces end to turn the body around that point in opposite directions, the body has no tendency to rotate. Any unbalanced moment causes rotation.

Mechanical Elements.—As before stated, all machinery can be analyzed into six elements, which are—*the lever, the wheel and axle, he inclined plane, the wedge, the pulley,* and *the screw.* These elements in no sense can create force; they only allow us to direct it and to use it to advantage.

Levers.—Levers are classified into three different kinds or orders. When the fulcrum is between the force and the weight, the lever is called a lever of the first order; when the weight is between the force and the fulcrum, the lever is of the second order; when the force is between the weight and the fulcrum, the lever is of the third order. The levers of safety-valves for steam-boilers belong to this last class.

The lever is an inflexible bar, by the application of which one Force may balance or overcome another. These forces are termed, respectively, the *power* and the *resistance* or *weight,* not from any difference in the action of the forces, but with reference merely to the intention with which the machine is used; and, indeed, the same terms are used about all the other mechanical elements. In applying the rod to operate upon any resistance, it must rest upon a centre prop, or fulcrum, somewhere along its length, upon which it turns in the performance of its work. Thus, there are three points in every lever to be regarded in examining its action—namely, the points of application of the power, the weight, and the point resting on the fulcrum. There is a certain relation to be observed between the magnitudes of the opposing force and the distances from the fulcrum—*namely,* that in every case the

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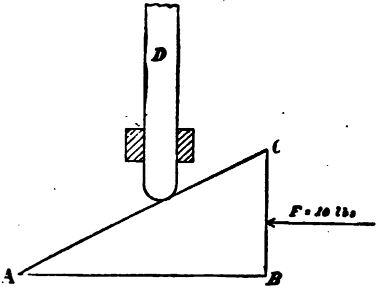
[*] *Note that the power above is really* a force of so many pounds, and not *echanical power as previously defined.*

power *multiplied* by its distance from the fulcrum is equal to t weight *multiplied* by its distance from the same point. This another statement of the principle of moments. Make the mome of the one force about the fulcrum equal to the moment of t other force, and solve for the quantity which is unknown.

Examples.—If with a crowbar pivoted on a stone we are tryi to raise up a large stone weighing, say, 1000 pounds. From t point of the crowbar to the pivot or fulcrum is 1 foot. From t fulcrum to where the handle is grasped is, say, 4 feet. Wh force must be exerted to lift up the stone? Call this force for shortness. Taking moments about the fulcrum, we ha $f \times 4 = 1000 \times 1$, or $4f = 1000$ pounds. Therefore, dividing bo sides of our equation by 4, we have f the force to be exerted 250 pounds. If, instead of 1 foot, the distance from point to fi crum were 1 inch, the force f would be only one-twelfth of 2 pounds, or 20 pounds 13 ounces and a trifle over. By the aid levers enormous weights can thus be moved by the application comparatively small forces. No power is gained, for while t force to be applied in the second case is 12 times as small, t hand applying it moves through a distance 12 times as great in the first case.

The Wheel and Axle.—The wheel and axle may be consider as a perpetual lever, from the constant renewal of the points suspension and resistance. The fulcrum is the centre of the ax the longer arm is the radius of the wheel, and the shorter arm t radius of the axis. As the diameters of different circles bear t same proportion to each other that their respective circumferenc do, the power is also to the weight as the diameter of the wheel to the diameter of the axle. If one wheel move another of equ circumference, no power will be gained, as they will both mo equally fast. But if one wheel move another of different dia eter, whether larger or smaller, the velocities with which th move will be inversely as their diameters, circumferences, or nu ber of teeth.

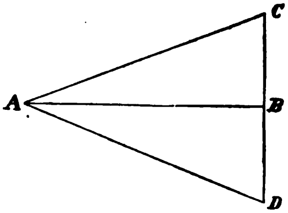
The Inclined Plane in its action of a small force balancing may best be understood by considering it from the stand- work or energy. ıed plane $A\ B\ C$ is gainst the column ›rce of 10 pounds. $A\ B$ is, say, 12 ıd $B\ C$ 4 inches. ıt a weight on the), which moves be- ides, can be raised g losses in friction. we start with the



ust entering and apply the 10-pound force till the point touching the column. The force of 10 pounds has been ver a distance of 12 inches. The work done is 10×12 inch- The weight of the column D has been raised 4 inches, or one- ›ne foot. The work done = weight times distance = $W \times 4$ ıds. Assuming no friction losses, the work done by the ›ounds must equal the work done on the column, there- $= 10 \times 12$, or $\frac{W}{10} = \frac{12}{4}$—*i. e.*, in general, the weight raised 'orce applied as the length of the horizontal side is to the the vertical side. Making the inclined plane less abrupt the gain in force. The general equation $\frac{W}{F} = \frac{\text{length } A\ B}{\text{length } B\ C}$ ıy one of the four quantities, W, F, $A\ B$, or $B\ C$, to be l if the other three are known. For instance, suppose it ›d to raise a weight of 2000 pounds and the greatest force l be applied was 200 pounds, what should be the relation he two perpendicular sides of the wedge? Here $W = 2000$ '00. By the equation

$$\frac{A\ B}{B\ C}, \text{ or } \frac{A\ B}{B\ C} = \frac{2000}{200} = \frac{10}{1}; \text{ therefore } A\ B = 10 \times B\ C.$$

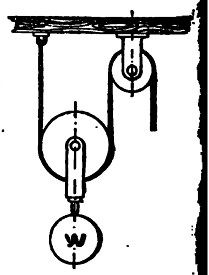
'**edge** is a double inclined plane, and is hence governed by exactly the same principles. The form of the equatio becomes



$$\frac{W}{F}=\frac{AB}{CD}.$$

The Pulley.—Pulleys are of two kinds, *fixed* and *movable*. The fixed pulley turns only upon its axis, and if the applied force is downward the weight is lifted through the same distance through which the force is applied. There is no mechanical advantage in this form, it merely serving to reverse the direction of a force.

The movable pulley turns on its axis and also rises and falls. The figure shows such a pulley in combination with a fixed pulley. The advantage gained by a movable pulley can best be seen by considering it from the standpoint of work done. Assume that there is no loss in friction of bearings and stiffness of rope, and recollect that the fixed pulley has no effect except to change the direction of the applied force. We may then consider that one end of the rope is fixed and a force of F pounds is applied at the other end, and that this force is pulling upward and trying to raise the weight W pounds. What is the relation between the values of F and W? Suppose F acts long enough so that the rope end moves two feet. The work done by the force F is $2F$ foot-pounds. The weight W will evidently be raised only one-half of two feet, or one foot, and the work done on W will be $W \times 1$, or W foot-pounds. These two amounts of work must be equal, since there is assumed to be no loss in friction; therefore $2F = W$, or $F = \frac{1}{2}W$. That is, by the use of one movabl pulley we can raise a weight of 100 pounds by applying a force o *50 pounds. It takes*, however, just twice as long to do it as if *raised the weight* without using the pulley.

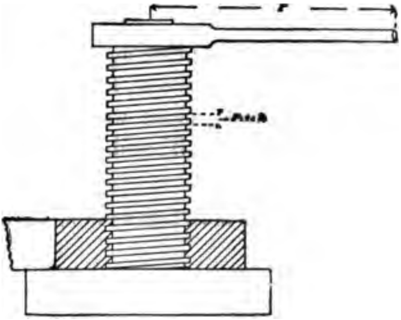


If we had two movable pulleys, 25 pounds would raise 100 ounds; with four movable pulleys 12½ pounds would raise 100 ounds, and so on.

The ordinary block and tackle consists of a fixed pulley of one r more sheaves, and a movable pulley of several sheaves. The ction of the movable pulley of 2 sheaves is the same as two movble pulleys, with 3 sheaves as three pulleys, and so on. Hence o find with a certain tackle what force must be applied to lift a ertain weight, divide the weight by twice the number of sheaves n the movable pulley.

The Screw.—The screw is another modification of the inclined lane, and it may be said to remove the same kind of practical nconveniences incidental to the use of the latter that the pulley oes in reference to the simple lever. The lever is very limited in he extent of its action and so is the inclined plane. But the puley multiplies the extent of the action of the lever, by presenting, n effect, a series of levers acting in regular succession; and just uch a purpose is effected by the screw. It multiplies the extent f the action of the inclined plane by presenting, in effect, a coninued series of planes.

The *screw*, in principle, is that of an inclined plane wound ound a cylinder, which enerates a spiral of uniorm inclination, each revlution producing a rise r traverse motion equal o the pitch of the screw —that is, the distance etween two consecutive hreads.



As in cases of other lements, the relation beween applied force and eight raised is easily *obtained by looking at it from the standoint of work.*

In the figure a force F is applied at the end of a lever. distance from the point of application of F to the centre o screw is r inches. Suppose F is applied through one revol of the screw raising a weight W attached to its end a distaı inches equal to the pitch of the screw.

The force F does work to the amount of $2 \times 3.1416 \times r \times 1$ $2 \times 3 \times 3.1416 \times r$ is the distance through which F acts. Wo done on the weight W to an amount $W \times P$.

$$\text{Therefore } 2 \times 3.1416\, r\, F = W P, \quad \text{or} \quad F = \frac{W P}{6.2832\, r}.$$

Example.—What force must be applied at the end of the of a jackscrew to raise a weight of 2000 pounds, if the lever is 2 feet and the pitch of the screw ½ inch.

$$F = \frac{2000 \times \frac{1}{2}}{6.2832 \times 2 \times 12} = 6.63 \text{ pounds.}$$

Example.—If a force of 10 pounds be applied at the end o lever, what weight will it lift?

$$W = \frac{6.2832\, r\, F}{P} = \frac{6.2832 \times 2 \times 12 \times 10}{\frac{1}{2}} = 3016 \text{ pounds.}$$

Example.—If the lever be 4 feet long, what will be the w lifted? *Ans.* By doubling the length of lever the same for 10 pounds, applied at its end, will lift double the weight, or pounds.

If the screw be applied against a toothed wheel as in a w we have a combined screw, lever, and axle. To get the rel between force and weight we calculate separately for the v and axle the value of W, and substitute this value in the equ for the screw above.

Note that P and r must both be in inches or feet.

CHAPTER II.

GENERATION AND TRANSMISSION OF POWER.

Sources of Power.—While, as explained under "Conservation of Energy," the ultimate or fundamental source of energy is in he sun's rays, these are not used directly by man. The principal econdary sources of power are the tides operating some form of ide-mill, the wind, waterfalls, carbon in its different forms, such as coal, petroleum, or gas, and various chemicals used in electrical batteries. Of these, water-power and carbon power are the two most important. We may further say that while there are many hot-air or gas engines in use, yet practically all the carbon power is derived by means of the steam boiler and steam engine.

Amounts of Power Used in Various Operations.

Description of Works.	Work-hrs. per day	Force. F	Veloc'y V	Ft.-lbs. per sec.	Horses. H
A man can raise a weight by a single fixed pulley,	6	50	0.8	40	0.072
A man working a crank,	8	20	2.5	50	0.090
A man on a tread-wheel (horizontal),	8	144	0.5	72	0.130
A man in a tread-wheel (axis 24° from vertical),	8	30	2.3	69	0.125
A man draws or pushes in a horizontal direction,	8	30	2	60	0.109
A man pulls up or down,	8	12	3.7	44.4	0.080
A man can bear on his back,	7	95	2.5	237.5	. . .
A horse in a horse-mill, walking moderately,	8	106	3	318	0.677
A horse in a horse-mill, running fast,	5	72	9	648	1.178
An ox in a horse-mill, walking moderately,	8	154	2	308	0.558
A mule " " "	8	71	3	213	0.303
An ass " " "	8	33	2.65	87.4	0.160
On bad Foot-roads.					
A man can bear,	10	50	3.5	175	
Llama of Peru can bear,	10	100	3.5	350	
Donkey can bear,	10	200	3.5	700	
Mule can bear,	10	400	5	2000	

ANIMAL POWER.

Work of a Man against Known Resistances. (Rankine.)

Kind of Exertion.	R, lbs.	V, ft. per sec.	$\frac{T''}{3600}$ (hours per day).	RV, ft.-lbs. per sec.	RVT, ft.-lbs. per day.
1 Raising his own weight up stair or ladder	143	0.5	8	72.5	2,088,000
2. Hauling up weights with rope, and lowering the rope unloaded	40	0.75	6	30	648,000
3. Lifting weights by hand... ..	44	0.55	6	24.2	522,720
4 Carrying weights up-stairs and returning unloaded....	143	0.13	6	18.5	399,600
5 Shovelling up earth to a height of 5 ft. 3 in	6	1.3	10	7.8	280,800
6. Wheeling earth in barrow up slope of 1 in 12, ½ horiz. veloc. 0.9 ft. per sec. and returning unloaded.........	132	0 075	10	9.9	356,400
7 Pushing or pulling horizontally (capstan or oar).......	26.5	2.0	8	53	1,526,400
8. Turning a crank or winch . .	12.5	5.0	?	62.5	....
	18.0	2.5	8	45	1,296,000
	20.0	14 4	2 min.	288	....
9. Working pump..	13.2	2.5	10	33	1,188,000
10. Hammering.................	15	?	8?	?	480,000

EXPLANATION.—R, resistance; V, effective velocity = distance through which R is overcome ÷ total time occupied, including the time of moving unloaded, if any; T', time of working, in seconds per day; $T' \div 3600$, same time, in hours per day; RV, effective power, in foot-pounds per second; RVT, daily work.

Performance of a Man in Transporting Loads Horizontally. (Rankine.)

Kind of Exertion.	L, lbs.	V, ft.-sec.	$\frac{T}{3600}$ (hours per day).	LV, lbs. conveyed 1 foot.	LVT, lbs. conveyed 1 foot.
11. Walking unloaded, transporting his own weight........	140	5	10	700	25,200,000
12. Wheeling load L in 2-whld. barrow, return unloaded..	224	$1\frac{2}{3}$	10	373	13,428,000
13. Ditto in 1-wh. barrow, ditto..	132	$1\frac{2}{3}$	10	220	7,920,000
14. Travelling with burden......	90	$2\frac{1}{2}$	7	225	5,670,000
15. Carrying burden, returning unloaded	140	$1\frac{2}{3}$	6	233	5,032,800.
16. Carrying burden, for 30 seconds only....	252	0	... ...	0	....
	126	11 7	......	1474.2	....
	0	23.1	....	0	....

EXPLANATION.—L, load; V, effective velocity, computed as before; T', *time of working, in seconds per day*; $T'' \div 3600$, same time in hours per day; LV, *transport per second*, in lbs. conveyed one foot; LVT, daily transport.

Work of a Horse against a Known Resistance. (Rankine.)

Kind of Exertion.	R.	V.	$\frac{T.}{3600}$	RV.	RVT.
1. Cantering and trotting, drawing a light railway carriage (thoroughbred)........ ..	min. 22½ mean 30½ max. 50	14⅔	4	447½	6,444,000
2. Horse drawing cart or boat, walking (draught-horse)....	120	3.6	8	432	12,441,600
3. Horse drawing a gin or mill, walking	100	3.0	8	300	8,640,000
4. Ditto, trotting	66	6.5	4½	429	6,950,000

EXPLANATION.—*R*, resistance, in lbs.; *V*, velocity, in feet per second; *T*' ÷ 3600, hours work per day; *RV*, work per second; *RVT*, work per day.

The average power of a draught-horse, as given in line 2 of the above table, being 432 foot-pounds per second, is 432/550 = 0.785 of the conventional value assigned by Watt to the ordinary unit of the rate of work of prime movers. It is the mean of several results of experiments, and may be considered the average of ordinary performance under favorable circumstances.

Performance of a Horse in Transporting Loads Horizontally. (Rankine.)

Kind of Exertion.	L.	V.	T.	LV.	LVT.
5. Walking with cart, always loaded....	1500	3.6	10	5400	194,400,000
6. Trotting, ditto....	750	7.2	4½	5400	87,480,000
7. Walking with cart, going loaded, returning empty; *V*, mean velocity..............	1500	2.0	10	3000	108,000,000
8. Carrying burden, walking...	270	3.6	10	972	34,992,000
9. Ditto, trotting	180	7.2	7	1296	32,659,200

EXPLANATION.—*L*, load in lbs.; *V*, velocity in feet per second; *T* ÷ 3600, working hours per day; *LV*, transport per second; *LVT*, transport per day.

This table has reference to conveyance on common roads only, and those evidently in bad order as respects the resistance to traction upon them.

Work of a Horse on a Grade.—If a horse can haul on a level 00 pounds, on a grade approximately the following loads can be hauled at the same speed:

With a rise of—

1 in 100	1 in 50	1 in 40	1 in 30	1 in 20	1 in 10
90 lbs.	81 lbs.	72 lbs.	64 lbs.	40 lbs.	25 lbs.

Power Required for Wood Working Machinery.

	Horse-Power running idle.	Horse-Pow doing fu work.
[illegible] diam. 12, speed [illegible] rev.	1.0	2.6
[illegible]	1.5	5.3
[illegible]	.8	8.9
[illegible]	2.1	18.8
[illegible] diam. [illegible]	.9	1.3
[illegible]	1.9	3.6
[illegible]	10.4	17.6
[illegible] speed [illegible] rev.	2.8	5.
[illegible]	1.4	3.8
[illegible]	1.4	2.5
[illegible]	.5	1.2
[illegible]	.8	1.1
[illegible] diam. [illegible]	[illegible]	2.0
[illegible]	[illegible]	2.9

[illegible] Machinery.

	[illegible]	Horse-Pow doing ful work.
[illegible]	[illegible]	.6
[illegible]	[illegible]	3.2
[illegible]	[illegible]	8.0
[illegible]	[illegible]	35.0
[illegible]	[illegible]	3.1
[illegible]	[illegible]	4.6
[illegible]	[illegible]	4.8

E FOR METAL WORKING MACHINERY (*continued*).

	Horse-Power running idle.	Horse-Power doing full work.
l, horizontal, 78'' swing, boring hole		
ı. in cast iron.................................	......	4.7
e 24''×13', two tool heads both cutting,		
kward 60' per min..............................	6.5	
'', feed $\frac{1}{32}$'', speed forward 10' per min.	2.1	8.0
ng reversal......................................	19.5	
e 36''×18', two tool heads both cutting,		
kward 80' per min..............................	4.7	
1'', feed $\frac{1}{2}$'', speed forward 20' per min.	3.9	16.7
ing reversal.....................................	22.1	
e 56''×35'', two tool heads both cut-		
d backward 111' per min......................	12.7	
$\frac{3}{8}$'', feed $\frac{5}{16}$, speed forward 18' per min.	7.1	13.7
ch reversal, during reversal..................	19.8	
:. stroke 22'', cutting steel die, 6'' stroke,		
ıte 1.7 sq. in. per min........................	......	.4
x. stroke 19'', one tool head, planing		
ron, 8'' stroke, speed forward 16 ft. per		
ward 32 ft. at max. stroke, cut $\frac{3}{4}$'', feed		
ı is very heavy work............................	1.8	9.7
chine, Brown & Sharp, No. 15, driven by		
....	0.5	2.2
:hine, 6'' diam. cutter, 13'' face, cutting		
deep...	1.2	11.8
chine, 40'' table, 15'' max. stroke, 18		
er min. with iron, cut $\frac{1}{2}$'', feed $\frac{3}{16}$'',		
vnward 23½' per min...........................	2.2	7.3
:hine, speed return 67½' per min.........	2.2	
chine, double head, one motor to each		
ke 9'', 15½ per min.............................	2.3	8.9
:hine, cut $\frac{1}{2}$'', feed $\frac{3}{16}$'', cast iron, speed		
l..	2.2	8.0
:hine, speed return..............................	2.3	
e for one motor....................................		
l screw cutting, 13½'' swing heavy cut.	.2	.5
e, 21'' swing, turning 5'' piece, cut $\frac{3}{16}$'',		
per min..	......	.25
ıe, 17'' swing, turning 2⅜'' steel shaft,		
eed 8'' per min....................................	......	.45
:l, 8'', 3000 rev....................................	......	1.6
31''×6'', linear *velocity 680 ft.* per min.	.3	1.6
42''×12'', " *1680* " "	.25	3.2

POWER REQUIRED FOR ROLLING MILL MACHINERY.

	Horse-Power running idle.	Horse-Pow doing fu work.
Lathe, Cambria, 61″ roll turning, 35″ roll, 42 rev. per hour	1.1	4.8
Lathe, Bement, 63″ roll turning, 35″ roll, 40 rev. per hour	1.4	4.8
Lathe, Bement, same starting up	10.8	
Lathe, Bement, 63″ roll turning, 28″ roll, 48 rev. per hour	1.5	5.9
Lathe, Garrison, 40″ roll turning, 39″ roll, 48 rev. per hour	1.6	6.7
Straightening press, working on rails 80 lbs. to yard, 41 strokes per min	3.0	14.8
Straightening press, same, starting	14.8	
Punch for rails, punching three 1¼″ diam. holes in ½″ metal at the rate of 34 strokes per min	......	3.0
Punch for rails, starting, on account of heavy fly-wheel	8.9	
Hot saw, cutting 20″ × ½″ I beams, speed 1800 per min., cut 2½ min	4.6	31.
Hot saw, cut 1 min	......	84.
" cut 55 sec	......	92.
Cold saw, Newton, on 80 lb. rails, diam. 20″, width $\frac{3}{16}$″, 192 teeth, 8 rev. per min	......	3.8

POWER CONSUMED BY STURTEVANT STEEL PRESSURE BLOWE WITH OUTLET FULLY OPEN.

Size blower.	4 oz. blast.		5 oz. blast.		6 oz. blast.		7 oz. blast.		8 oz. blast.	
	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.
2	3103	2.1	3445	3.0	3756	3.9				
3	2456	3.0	2743	4.2	3006	5.4				
4	2224	4.2	2470	5.7	2692	7.5				
5	1814	5.0	2026	8.4	2215	10.8	2387	13.8		
6	1619	7.8	1797	10.8	1960	14.1	2009	18.0	2258	21.
7	1344	10.8	1507	15.0	1641	19.5	1768	24.9	1898	31.
8	1200	13.5	1330	19.2	1445	25.2	1565	31.8	1675	39.
9	1035	17.7	1145	24.9	1250	32.7	1350	41.4	1446	50.
10	902	23.7	995	33.6	1085	43.5	1168	55.2	1253	67.

POWER USED BY FANS.

Size of Fan.	24	30	34	36	42	48	54	60	72
ubic feet per minute . .	1884	2940	3780	4236	5772	7536	9540	11778	16962
evolutions per minute .	310	247	220	206	177	155	137	124	103
orse-power.	.066	.103	.132	.148	.208	.271	.353	.435	.636
ubic feet per minute . .	2826	4410	5670	6354	8658	11304	14310	17667	25473
evolutions per minute .	464	372	332	310	265	232	206	185	155
orse-power.	.139	.258	.360	.413	.588	.792	1.000	1.253	1.870
ubic feet per minute . .	3768	5880	7560	8472	11544	15072	19080	23556	33924
evolutions per minute .	618	495	441	412	353	310	275	247	206
orse-power.	.256	.477	.650	.754	1.083	1.483	1.908	2.400	3.590
ubic feet per minute . .	4710	7350	9450	10590	14430	18840	23850	29445	42405
evolutions per minute .	773	620	552	515	441	386	343	308	258
orse-power.	.400	.735	1.012	1.165	1.700	2.350	3.250	3.820	5.780
ubic feet per minute . .	6280	9800	12600	14120	19240	25120	31800	39260	56540
evolutions per minute .	1030	822	734	685	586	514	456	410	342
orse-power.	.805	1.420	1.954	2.260	3.310	4.570	5.980	7.650	11.58

OWER REQUIRED FOR PIPE THREADING MACHINE.

	H.-P.
machine running light....................................	1.2
" "	1.5
1½″ pipe at 40 rev. of machine per min...............	2.0
2″ " 32 " " "	2.5
3″ " 21 " " "	2.7
4″ " 12 " " "	2.9
g 1½″ " 45 rev. per min., 22.4 lineal ft. per min.	2.2
2″ " 32 " " 20 " "	2.9
3″ " 21 " " 19 " "	3.1
4″ " 12 " " 14 " "	5.0

nethods of transmitting power are principally the fol-

Shafting with pulleys and belts.
Shafting with pulleys and ropes or rope driving.
Shafting and gear-wheels.
Shafting and friction clutches.
Pneumatic, by *compressed* air.
Electrical, by dynamos, line, and motors.

Shafting, which was formerly made of wrought iron, is n largely made of steel. It must be large enough to transmit t desired power without being twisted too much, and it must a be large enough to stand the pull of belts, its own weight, a the weight of pulleys, without being deflected or bent enough cause trouble. The hangers or shaft supports should, of cour be placed as close as possible to the pulleys, and should be, general, for light shafting not over 8 feet apart.

The following two formulæ will give the necessary sizes of sha and allowable distance of hangers for either rolled iron or st shafting.

Let R = number of revolutions per minute, $H.P.$ = number horse-power to be transmitted, d = diameter of shaft, and L = d tance in feet between the hangers; then

$$d=\sqrt[3]{\frac{70\,H.P.}{R}}, \quad \text{or} \quad H.P.=\frac{d^3R}{70}.$$

$$L=\sqrt[3]{140\,d^2}, \quad \text{or} \quad d=\sqrt{\frac{L^3}{140}}.$$

These formulæ are short methods of expressing the followi rules:

To find the diameter of a shaft to transmit a certain hor power at a certain speed, multiply the horse-power by 70 a divide by the number of revolutions per minute and find the cu root of the quotient; or

To find the horse-power which a certain shaft will transmit a given speed, multiply the cube of the diameter by the rev lutions per minute and divide by 70.

To find the allowable distance between hangers, multiply t square of the diameter by 140 and find in the tables the cube r of the product.

The first formula gives the size of shaft to transmit a cert number of horse-power at a certain speed. The second or low formula tells how near together the hangers must be for that s of shaft. If it is not possible to put the hangers as near as he shaft must be made larger and its diameter will be found by sing the second formula.

Example.—What size of shaft is necessary to transmit 100 H.P. at 200 rev. per minute? Taking the first formula we have $d = \sqrt[3]{\frac{70 \times 100}{200}} = \sqrt[3]{35}$. Looking in a table of cube roots we find that $\sqrt[3]{35}$, or $d, = 3.27''$.

Suppose we find that the hangers cannot be placed nearer than 10 feet. To see if the diameter 3.27″ is enough, take the second formula $d = \sqrt[3]{\frac{L^3}{140}} = \sqrt[3]{\frac{10 \times 10 \times 10}{140}}$, or $d = \sqrt[3]{7.1} = 2.66''$. From this we see that the 3.27″, or 3¼″, shaft will be strong enough even with the hangers at 10 feet distance apart.

Belting.—While there are several methods of connecting shafts so that one turns the other, the most common way is by means of belts.

Rubber and leather belts.—Rubber belts will transmit nearly as much power as leather belts with the same tension; and they have this advantage, that they may be made of any length, width, or thickness, and yet always run straight, providing the pulleys are in line. Besides, their first cost is much less than those of leather; but they will not last over half as long. They cannot be run in situations where the belt rubs, nor as cross-belts, or through forks, as shifting-belts; and when they give out, it is almost impossible to repair them.

If a rubber belt runs off, and becomes entangled in the machinery, ten chances to one it will be completely ruined; whereas, a leather belt, under like circumstances, will sustain very little injury. When saturated with oil, they soon rot, and when situated in cold, damp places, they are liable to freeze, which has a dency to separate the different thicknesses and ruin the belt. ides, they often *freeze to the face* of pulleys when standing , *and when started up, the gum facing is torn off, which ruins e belt.*

2

A leather belt, if made of good stock, not overstrained a properly treated, will last for twenty years. When partly wo out, it may be cut up and used over again for a narrower shorter belt; and when entirely unfit for the transmission of pow it may be used for different purposes around a factory; but wh rubber belts are worn out, they are of no value whatever.

Belts derive their power to transmit motion from the frictio between the surface of the belt and the pulley, and from nothin else, and are governed by the same laws as in friction between fl surfaces. The friction increases regularly with the pressure. Th great difference often observed in the friction of belts is due simpl to their elasticity of surface; that is, the more elastic the surfa the greater the friction.

In taking power from any source of motion, there are two poin which control us; all the others we can control and modify to certain extent. Ordinary belts will sustain safely a working te sion of 45 lbs. per inch in width; the rule to determine the widt of belt and size of pulley required to transmit a given horse-pow is easily found. Since a horse-power is 33,000 pounds raised on foot high per minute, we must adjust the width and velocity o belts so as to effect the required result. Thus, if the belt mov with a velocity of 733 feet per minute, a belt five inches wid will transmit five horse-power, provided the effective tension is 4 lbs. per inch. If the velocity be increased to 1466 feet per mi ute, the same belt with the same tension will transmit ten hors power. So that a five-inch belt, applied to a five-foot pulley mak ing 120 revolutions per minute, would transmit ten horse-pow when the effective tension is 225 pounds.

By taking the actual effective tension of the belt, and multiply ing it by the actual velocity, we get what may be called the in dicated horse-power of the belt, which corresponds to the indicate horse-power of the engine. And, finally, by measuring the ac ual power transmitted — which may be done by means of a dyn *amometer — we can get* the actual power transmitted. Rul *based upon the amount* of belt surface in contact with the pulle on similar data, cannot be made to give reliable results. For ctical purposes, velocity and power to resist tension are the y available elements of the calculation. Actual tension, adhe- n, friction, etc., can all be varied at will, and consequently form certain dependence for the calculations of the machinist and ineer.

n the scientific principle that the adhesion, and consequently capability of leather belts to transmit power from motors to chines, is in proportion to the pressure of the actual weight of leather on the surface of the pulley, it is manifest that, as ger belts have more weight than shorter ones, and that broader ts of the same length have more weight than narrower ones, it y be adopted as a rule that the adhesion and capability of belts transmit power are in the ratio of their relative lengths and adth. A belt of double the length or breadth of another der the same circumstances, will transmit more than double the wer. For this reason it is desirable to use long belts. By ubling the velocity of the same belt, its effectual capability for nsmitting power is also doubled.

Good stock is the first requirement of a belt, which, if spongy, ll not meet that demand. It must be firm, but pliable; the in or hair side should be free from wrinkles; the stock should w no irregularities in dressing, but be of an even thickness oughout; the splices should be mathematically true, and if ets are employed, they should be inserted on the hair side, and burrs sent home before riveting; the edges should be parallel d perfectly straight. In handling a belt, examine it carefully, uble it up, the hair side out, and press it together; if it crack der this treatment, it should be rejected, as the rational use of a lt consists in utilizing the whole amount of power it will trans- t.

Belts are sometimes used having a transmitting power of double capacity necessary where they are employed, while quite as en they *are much too narrow* for the work required of them. *first instance shows a* useless waste of material, the latter

poor economy; as, in order that it may perform the work requ
it is necessary frequently to take it up, as a result of whic
weak points succumb to the strain, and it is torn asunder;
not, the shaft is likely to be drawn out of line, or the bearing
heated.

In using a new belt a few days, if it present a mottled ap
ance on the side next to the pulleys, it may be set down that
not furnishing the full capacity of its power. The spots ref
to indicate that certain portions of the belt do not touch
pulley, and that its entire transmitting power is not utilized.
the face of the pulley is true, and the belt is as nearly perfe
possible, the defect may be remedied by the judicious applic
of rendered tallow and fish oil, two parts of tallow to one o
melted and allowed to cool. A new belt should be used a d
two before it is oiled, and frequent application of small quan
are better than too liberal oiling at long intervals.

If a belt, of the proper size for the work it has to do, slip o
pulley, it is caused by the centrifugal force, which tends to t
it outward; a corresponding degree of tension will check
defect.

Belts should be put on by a person acquainted with their
as the wear of the belt depends considerably on the mann
which it is put on; therefore, the following suggestions, if
tised, will be of much service to persons employed in this ca
ity. The ends to be joined should be cut perfectly squar
order that one side may not be drawn tighter than the o
Good lace-leather, if properly used, will give better satisfa
than any patent fastening.

Where belts run vertically, they should always be drawn m
ately tight, or the weight of the belt will not allow it to ad
closely to the lower pulley; but in all other cases they shoul
slack. In many instances, the tearing out of lace-holes is unj
attributed to poor belting; when, in reality, the fault lies in ha
a belt too short, and trying to force it together by lacing, and

ore the leather has stretched while being manufactured, the more able it is to be complained of.

How to test the quality of leather for belting.—Cut a small trip of the leather about $\frac{1}{16}$ of an inch in thickness, and place it n strong vinegar. If the leather has been thoroughly tanned, nd is of good quality, it will remain for months even immersed, ithout alteration, simply becoming a little darker in color. But, n the contrary, if not thoroughly tanned, the fibres will quickly well, and, after a short period, become transformed into a gelainous mass.

How to make belts run on the centre of pulleys.—It is a common occurrence for belts to run on one side of the pulleys. This rises from one or two causes: 1st, One or both of the pulleys may be conical, and, of course, the belt will run on the higher ide. The most effectual remedy for this will be to straighten he face of the pulleys. 2d, The shafts may not be parallel or xactly in line. In this case the belt will incline off to the side where the ends of the shafts come the nearest together. The remdy in this case would be to slack up on the hanger-bolts, and drive the hangers out or in, as the case may be, until both ends of he shafts become exactly parallel. This can be determined by getting the centres of the shafts at both ends by means of a long lath or light strip of board.

Tighteners.—The tightener should be placed as close to the large or driving-pulley as circumstances will permit, as the loss of power incurred by the use of the tightener is equal to that required to bend the belt and carry the tightening-pulley. Consequently, there is a greater loss of power by placing it near the small pulley, as the belt is required to be bent more than when it is placed near the large one.

The reason why belts run to the highest side of a pulley is due, in part, to centrifugal force, and also to the fact that the part of belt nearest the highest part of a rounded pulley is more raply drawn, *because the circumference* of the pulley is greater at *hat point.*

Length of Belt.—To find the length of belt necessary to nect two pulleys, of course the simplest and most accurate me is to measure it. If, however, it is necessary to ascertain it be the pulleys are in place, the following rules may be applied:

Open Belt.—Add together the diameters of the two pulleys multiply the sum by 3.1416; to half the product thus obta add twice the distance between centres of shafts. If the pul are of the same diameter, or nearly so, the result obtained by rule will be accurate, otherwise it will be slightly too small.

Crossed Belt.—Divide the sum of the diameters of the two leys by twice the distance between centres and to the quotient obtained add 1.571. Multiply this sum by the sum of the di eters of the two pulleys, and to the product add twice the dist between centres. The result will very closely agree with the length required, the result being the more accurate the greater distance between centres.

Example.—18″ pulley and 12″ pulley, 20 feet between cen

$$\text{Open belt} = \frac{(1.5+1)\ 3.1416}{2} + 2 \times 20 = 43'\ 11''.$$

$$\text{Crossed belt} = \left(\frac{1+1.5}{2 \times 20} + 1.571\right)\ 2.5 + 40 = 44'\ 1''.$$

To calculate the width of belt to transmit a given horse-p there are various rules which give results differing consider from each other. This is because different writers are not ag as to the safe allowable strain to put on a belt, nor as to the tive value of double and single belts. The faster the belt runs more power it will transmit at a certain degree of tightness, so a 2-inch belt, with a speed of 2000 feet per minute, will tran safely twice the power that it will at 1000 feet per minute.

Allowance must be made for special cases, such as quarter t crossed, vertical belts, and belts running from very large to small pulleys.

The following tables give the speed in feet per minute various sized pulleys and rotary speeds. The ordinary veloci for belts are between 2000 and 5000 feet per minute.

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, or of Circumference of Revolving Wheels or Pulleys.

Diam. Pulley.	Revolutions per Minute of Wheel or Pulley.									
	110	120	130	140	150	160	170	180	190	200
Inches.	V	V	V	V	V	V	V	V	V	V
1	.47996	.52360	.56723	.61086	.65450	.69818	.74176	.78540	.82903	.87266
2	.95993	1.0472	1.1345	1.2217	1.3090	1.3963	1.4835	1.5708	1.6581	1.7453
3	1.4399	1.5708	1.7017	1.8326	1.9635	2.0944	2.2253	2.3562	2.4870	2.6180
4	1.9199	2.0944	2.2689	2.4435	2.6180	2.7925	2.9671	3.1416	3.3160	3.4906
5	2.3998	2.6180	2.8362	3.0543	3.2725	3.4907	3.7088	3.9270	4.1451	4.3633
6	2.8800	3.1416	3.4034	3.6652	3.9270	4.1888	4.4506	4.7124	4.9742	5.2360
7	3.3597	3.6652	3.9706	4.2760	4.5815	4.8869	5.1924	5.4978	5.8032	6.1086
8	3.8397	4.1888	4.5378	4.8869	5.2360	5.5851	5.9341	6.2832	6.6322	6.9813
9	4.3196	4.7124	5.1051	5.4978	5.8905	6.2832	6.6759	7.0686	7.4612	7.8540
10	4.7996	5.2360	5.6723	6.1086	6.5450	6.9813	7.4177	7.8540	8.2903	8.7266
11	5.2796	5.7596	6.2395	6.7195	7.1990	7.6794	8.1994	8.6394	9.1193	9.5992
12	6.7596	6.2832	6.8068	7.3304	7.8540	8.3776	8.9012	9.4248	9.9488	10.472
13	6.2395	6.8060	7.3740	7.9412	8.5085	9.0757	9.6429	10.210	10.777	11.345
14	6.7195	7.3304	7.9412	8.5521	9.1630	9.7738	10.385	10.996	11.606	12.217
15	7.1995	7.8540	8.5085	9.1630	9.8175	10.472	11.126	11.781	12.435	13.090
16	7.6794	8.3776	9.0757	9.7738	10.472	11.170	11.868	12.566	13.264	13.963
18	8.6394	9.4248	10.210	10.996	11.781	12.566	13.352	14.137	14.422	15.708
20	9.5993	10.472	11.345	12.217	13.090	13.963	14.835	15.708	16.580	17.453
21	10.079	10.966	11.912	12.828	13.744	14.661	15.577	16.493	17.409	18.326
24	11.519	12.566	13.613	14.661	15.709	16.755	17.802	18.850	19.897	20.944
27	12.959	14.137	15.316	16.493	17.671	18.850	20.027	21.206	22.384	23.562
30	14.399	15.708	17.017	18.326	19.635	20.944	22.253	23.562	24.871	26.180
33	15.839	17.278	18.718	20.159	21.597	23.038	24.478	25.918	27.358	28.798
36	17.280	18.850	20.420	21.991	23.562	25.133	26.704	28.274	29.845	31.416
39	18.719	20.420	22.122	23.824	25.525	27.227	28.929	30 631	32.332	34.084
42	20.159	21.992	23.824	25.656	27.489	29 322	31.154	32.987	34.819	36.652
45	21.599	23.562	25.525	27.489	29.452	31 416	33.379	35.343	37.306	39.270
48	23.039	25.132	27.227	29.322	31.416	33.510	35.605	37.699	39.792	41.888
51	24.579	26.704	28.929	31.154	33.379	35.605	37.830	40.055	42.279	44.506
54	26.019	28.274	30.621	32.987	35.343	37.699	40.055	42.411	44.767	47.124
60	28.800	31.416	34.034	36.652	39.270	41.888	44.506	47.124	49.742	52.360
66	31.678	34.558	37.437	40.317	43.197	46.077	48.956	51.836	54.716	57.596
72	34.557	37.700	40.841	43.982	47.124	50.265	53.407	56.549	59.690	62.832
78	37.437	40.840	44.244	47.647	51.050	54.454	57.858	61.261	64.664	68.068
84	40.317	43.984	47.647	51.313	54.980	58.643	62.308	65.973	69.639	73.304
90	43.197	47.125	51.051	54.978	58.905	62.832	66.759	70.686	74.613	78.540
96	46.076	50.264	54.454	58.643	62.830	67.021	71.209	75.398	79.587	83.776
102	48.956	53.404	57.858	62.308	66.760	71.209	75.660	80.111	84.561	89.012
108	51.836	56.548	61.261	65.973	70.685	75.398	80.111	84.823	89.535	94.248
114	54.716	59.692	64.664	69.638	74.615	79.587	84.561	89.535	94.509	99.484
120	57.595	62.832	68.068	73.304	78.540	83.776	89.012	94.248	99.484	104.72
126	60.476	65.972	71.471	76.969	82.465	87.965	93.462	98.960	104.46	109.95
132	63.355	69.116	74.875	80.634	86.395	92.153	97.913	103.67	109.43	115.19
138	66.235	72.256	78.278	84.299	90.320	96.342	102.36	108.38	114.41	120.43
144	69.115	75.400	81.681	87.965	94.250	100.53	106.81	113.10	119.38	125.66
150	71.995	78.540	85.085	91.630	98.175	104.72	111.26	117.81	124.35	130.90
160	76.794	83.776	90.757	97.738	104.72	111.70	118.68	125.66	132.64	139.63
180	86.394	94.248	102.10	*109.96*	*117.81*	*125.66*	133.52	141.37	149.22	150.08
200	*87.266*	*104.72*	*113.45*	*122.17*	*130.90*	*139.63*	148.35	157.08	165.80	174.53
240	*115.19*	*126.66*	*136.13*	*146.61*	*157.08*	*167.55*	178.02	188.50	198.97	209.44

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, Circumference of Revolving Wheels or Pulley

Diam. Pulley.	Revolutions per Minute of Wheel or Pulley.								
	210	220	230	240	250	260	270	280	290
Inches.	V	V	V	V	V	V	V	V	V
1	.91630	.95993	1.0035	1.0472	1.0908	1.1345	1.1781	1.2218	1.265
2	1.8326	1.9199	2.0071	2.0944	2.1816	2.2689	2.3562	2.4435	2.530
3	2.7489	2.8798	3.0107	3.1416	3.2724	3.4034	3.5343	3.6652	3.796
4	3.6652	3.8397	4.0142	4.1888	4.3633	4.5378	4.7124	4.8869	5.061
5	4.5814	4.7997	5.0178	5.2360	5.4580	5.6723	5.8905	6.1086	6.326
6	5.4977	5.7596	6.0214	6.2832	6.5450	6.8068	7.0686	7.3304	7.592
7	6.4140	6.7195	7.0249	7.3304	7.6335	7.9412	8.2467	8.5521	8.857
8	7.3303	7.6794	8.0285	8.3776	8.7265	9.0757	9.4248	9.7738	10.12
9	8.2466	8.6394	9.0320	9.4248	9.8175	10.210	10.603	10.995	11.38
10	9.1610	9.5993	10.036	10.472	10.908	11.345	11.781	12.218	12.65
11	10.079	10.559	11.039	11.519	11.999	12.479	12.959	13.439	13.91
12	10.996	11.519	12.043	12.566	13.090	13.613	14.137	14.660	15.18
13	11,912	12.479	13.046	13.615	14.180	14.748	15.315	15.882	16.45
14	12.828	13.439	14.050	14.662	15.271	15.882	16.493	17.104	17.71
15	13.744	14.399	15.052	15.709	16.362	17.017	17.671	18.326	18.98
16	14.661	15.359	16.054	16.776	17.453	18.151	18.850	19.548	20.24
18	16.493	17.279	18.061	18.851	19.635	20.420	21.206	21.991	22.77
20	18.326	19.199	20.071	20.944	21.816	22.689	23.562	24.435	25.30
21	19.242	20.159	21.748	21.991	22.907	23.824	24.790	25.656	26.57
24	21.991	23.038	24.085	25.133	26.180	27.227	28.274	29.321	30.36
27	24.740	25.918	27.096	28.274	29.452	30.630	31.800	32.987	34.16
30	27.489	28.798	30.107	31.416	32.725	34.034	35.343	36.652	37.961
33	30.238	31.678	33.117	34.558	35.997	37.437	38.877	40.317	41.757
36	32.987	34.557	36.128	37.699	39.270	40.841	42.412	43.982	45.55
39	35.735	37.437	39.138	40.841	42.542	44.244	45.946	47.647	49.34
42	38.485	40.317	42.149	43.982	45.815	47.647	49.480	51.313	53.14
45	41.233	43.197	45.160	47.124	49.085	51.051	53.014	54.978	56.941
48	43.982	46.077	48.171	50.266	52.360	54.454	56.549	58.643	60.737
51	46.731	48.956	51.182	53.407	55,630	57.857	60.083	62.308	64.53
54	49.480	51.836	54.192	56.549	58.905	61.261	63.617	65.973	68.32
60	54.978	57.596	60.214	62.832	65.450	68.068	70.686	73.304	75.92
66	60.476	63.356	66.235	69.115	71.990	74.874	77.755	80.634	83.514
72	65.973	69.116	72.256	75.399	58.540	81.681	84.823	87.964	91.10
78	71.471	74.873	78.278	81.682	58.085	88.488	91.892	95.295	98.69
84	76.969	80.635	84.299	87.965	91.630	95.294	98.960	102.63	106.2
90	82.466	86.395	90.320	94.248	98.175	102.10	106.03	109.55	113.8
96	87.964	92.154	96.342	100.53	104.72	108.91	113.10	117.29	121.47
102	93.462	97.914	102.36	106.81	111.26	115.71	120.17	124.61	129.07
108	98.960	103.67	108.38	113.10	117.61	122.52	127,23	131.95	136.66
114	104.46	109.43	114.40	119.38	124.35	129.33	134.30	139.28	144.25
120	109.96	115.19	120.43	125.66	130.90	136.13	141.37	146.66	151.84
126	115.45	120.95	126.45	131.95	137.44	142.94	148.44	153.94	159.44
132	120.96	126.67	132.47	138.23	143.99	149.80	155.51	161.27	167.03
138	126.45	132.47	138.49	144.51	150.53	156.60	162.58	168.60	174.62
144	131.94	138.23	144.51	150.80	157.09	163.41	169.65	175.93	182.21
150	137.44	143.99	150.52	157.09	163.62	170.17	176.71	183.26	189.80
160	146.61	153.59	160.54	167.76	174.53	181.51	188.56	195.48	202.46
180	*164.93*	*172.79*	180.61	188.51	191.35	204.20	212.06	219.91	227.76
200	*183.26*	*191.99*	200.71	209.44	218.16	226.89	247.90	244.35	253.97
240	*219.91*	*230.38*	240.85	251.33	261.80	272.27	282.74	293.21	303.6

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, or of Circumference of Revolving Wheels or Pulleys.

Diam. Pulley.	Revolutions per Minute of Wheel or Pulley.									
	310	320	330	340	350	360	370	380	390	400
Inches.	V	V	V	V	V	V	V	V	V	V
1	1.3526	1.3963	1.4399	1.4835	1.5271	1.5708	1.6144	1.6581	1.7017	1.7454
2	2.7052	2.7925	2.8798	2.9761	3.0543	3.1416	3.2289	3.3162	3.4034	3.4906
3	4.0579	4.888	4.3197	4.4506	4.5815	4.7124	4.8433	4.9743	5.1051	5.2360
4	5.4105	5.5850	5.7596	5.9341	6.1080	6.2832	6.4577	6.6324	6.8068	6.9813
5	6.7632	6.9813	7.1995	7.4176	7.6360	7.8540	8.0722	8.2905	8.5085	8.7266
6	8.1158	8.3776	8.6394	8.9012	9.1630	9.4248	9.6866	9.948	10.210	10.472
7	9.4684	9.7738	10.079	10.385	10.690	10.996	11.301	11.606	11.912	12.217
8	10.821	11.170	11.519	11.868	12.217	12.566	12.915	13.265	13.613	13.963
9	12.174	12.566	12.959	13.352	13.744	14.137	14.530	14.922	15.315	15.708
10	13.526	13.963	14.399	14.835	15.271	15.708	16.144	16.581	17.017	17.453
11	14.879	15.359	15.839	16.319	16.798	17.279	17.759	18.239	18.718	19.198
12	16.232	16.755	17.279	17.802	18.326	18.850	19.373	19.897	20.420	20.944
13	17.584	18.151	18.719	19.286	19.853	20.420	20.988	21.555	22.122	22.690
14	18.937	19.548	20.159	20.769	21.384	21.991	22.602	23.213	23.824	24.434
15	20.289	20.944	21.599	22.253	22.907	23.562	24.216	24.872	25.525	26.180
16	21.652	22.340	23.038	23.736	24.434	25.133	25.831	26.530	27.227	27.296
18	24.347	25.133	25.918	26.704	27.489	28.274	29.060	29.846	30.630	31.416
20	27.052	27.925	28.798	29.671	30.543	31.416	32.289	33.162	34.034	34.906
21	28.405	29.321	30.238	31.154	32.071	32.987	33.903	34.820	35.735	36.652
24	32.463	33.510	34.558	35.605	36.652	37.699	38.746	39.795	40.841	41.888
27	36.521	37.699	38.867	40.055	41.234	42.412	43.590	44.769	45.946	47.124
30	40.579	41.888	43.187	44.506	45.815	47.124	48.433	49.743	51.051	52.360
33	44.637	46.077	47.507	48.956	50.395	51.836	53.276	54.717	56.156	57.596
36	48.695	50.265	51.826	53.407	54.980	56.549	58.119	59.691	61.261	62.832
39	52.753	54.454	56.146	57.858	59.560	61.261	62.963	64.666	66.366	68.068
42	56.810	58.643	60.466	62.308	64.140	65.974	67.806	69.640	71.471	73.304
45	60.868	62.832	64.786	66.759	68.720	70.686	72.649	74.614	76.576	78.540
48	64.926	67.020	69.105	71.209	73.305	75.398	77.493	79.589	81.681	83.776
51	68.984	71.209	73.425	75.660	77.885	80.111	82.336	84.563	86.787	89.012
54	73.042	75.398	77.745	80.111	82.465	84.823	87.179	89.537	91.892	94.248
60	81.158	83.776	86.394	89.012	91.630	94.248	96.866	99.486	102.10	104.72
66	89.274	92.153	95.033	97.913	100.79	103.67	106.55	109.43	112.31	115.19
72	97.389	100.53	103.67	106.81	109.95	113.10	116.24	119.38	122.52	125.66
78	105.51	108.91	112.31	115.72	119.12	122.52	125.93	129.33	132.73	136.14
84	113.62	117.29	120.95	124.62	120.28	131.95	135.61	139.28	142.94	146.61
90	121.74	125.66	129.59	133.52	137.44	141.37	145.30	149.22	153.15	157.08
96	129.85	134.04	138.23	142.42	146.61	150.80	154.99	159.17	163.36	167.55
102	137.97	142.42	146.87	151.32	155.72	160.22	164.67	169.12	173.57	178.02
108	146.08	150.80	155.51	160.22	164.93	163.65	174.36	179.07	183.78	188.50
114	154.20	159.17	164.15	169.12	174.20	179.07	184.05	189.02	193.99	198.97
120	162.32	167.55	172.79	178.02	183.26	188.50	193.73	198.97	204.20	209.44
126	170.31	175.93	181.43	186.92	192.42	197.92	203.42	208.92	214.41	219.90
132	178.55	184.31	190.07	195.83	201.58	207.35	213.10	218.87	224.62	230.38
138	186.66	192.68	198.71	204.73	210.75	216.77	222.79	228.82	234.83	240.86
144	194.78	201.06	207.35	213.63	219.91	226.19	232.48	238.76	245.04	251.32
150	202.89	209.44	215.99	222.53	229.07	235.62	242.16	248.72	255.25	261.80
160	216.52	223.40	230.38	237.36	244.34	251.33	258.31	265.30	272.27	279.26
180	243.47	251.33	259.18	267.04	274.89	282.74	290.60	298.46	306.30	314.16
200	270.52	279.25	287.98	296.71	305.43	314.16	322.89	331.62	340.34	349.06
240	284.05	335.10	345.58	356.05	366.52	376.99	387.46	397.95	408.41	418.88

A 2" belt will transmit twice as much power as a 1" belt, wh both are run at the same speed. Therefore, when we have fou what power a 1" belt will transmit at various speeds, we can g the power transmitted by any other width by multiplication.

The following table gives such values for single and dou [illegible] when the belt is open and horizonta

[illegible] Single and Double Belts at Various Speeds.

[illegible]	[illegible]	[illegible]	Speed [illegible]	H. P. Per 1" width single belt.	H. P. Per 1" width double belt.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.465
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.732
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.265
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.532
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.800
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.065
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.332
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.600
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.865
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.232
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.400
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.665
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.932
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.200
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.465
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.730
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.080
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.265
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.452
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.800
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.065
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.332

[illegible] open belt tran [illegible] making 510 rev [illegible] speeds we find th [illegible] per minut

; this speed a 1″ belt will transmit 4 H.P. A 10″ belt, there-re, will transmit 40 H.P.

Special cases, where the belts are crossed, vertical, or quarter rn, must have the results modified. The result as given above ust be multiplied by the figures in the following table:

	Multiplier.
Double horizontal, open belts	1.6
Single vertical, open belts	.8
Double vertical, "	1.2
Single horizontal, large to small pulleys	.2
Double horizontal, " "	.3
Quarter turn, single belts	.5
" double belts	.8

Example.—If the 10″ belt above were vertical, what would be ie horse-power which it could transmit safely?

Ans. 40 × .8 = 32 H.P.

Suppose also the driven pulley were much smaller than the 30″ river above, say 6″. Then if the belt were horizontal it would ansmit

$$40 \times .2 = 8 \text{ H.P., if single,}$$
$$40 \times .3 = 12 \text{ H.P., if double;}$$

id

$$40 \times .2 \times .8 = 6.4 \text{ H.P., if single vertical,}$$
$$40 \times .2 \times 1.2 = 9.6 \text{ H.P., if double vertical.}$$

To find the width of belt when the horse-power is given, first sume that the belt is horizontal and open and find width. Then it is crossed or vertical, *divide* the result by the proper number tained from the above table.

Example.—Wanted to transmit 100 H.P. from a 60″ pulley rning at 300 rev. per minute to a 30″ pulley, using a double lt; what width is necessary? The small pulley is nearly rtically above the large. What width belt will be neces-ry?

From *the table of belt speeds* we find that the speed in this

case is $78.54 \times 60 = 4712$ rev. per minute. At this sp
single horizontal belt will transmit 7.78 H.P. Therefore,
mit 100 H.P. we need 100 ÷ by 7.78, or a 12″ belt. But
belt runs vertical, we look up in the table of special cases
the number corresponding to this case to be .8. Dividin
.8, we get 15″ as the width of a single belt. But a do
will carry 1.6 times as much, so that we can use a do
15 ÷ 1.6, or 9″ belt.

Rule *for finding the change required in the length of a*
one of the pulleys on which it runs is changed for one of a
size.—Take three times the difference between the dia
the pulleys and divide by 2. The result will be the l
belt to cut out or put in.

How to measure a coil of belting.—Add the diamet
hole, in inches, to the outside diameter of the roll; mu
the number of coils in the roll; then multiply this by the
·1309, and the product will be the number of feet in the
have the exact length, the average diameter must be us
roll is not perfectly round, and fractional parts of an i
not be omitted in the calculation.

How to put on a belt.—Never place a belt on the
motion; always place it first on the loose pulley or the
rest; then run it on the pulley in motion. If the bel
heavy, and the pulleys run at a very high speed, it is adv
slack on the speed of the engine; but when this is impr
or inconvenient, care must be taken to mount the belt on
face. The person engaged in so doing must have a firm
and prevent his clothing from getting in contact either
belt or pulley. Where the belt is heavy, and the locat
that it is impossible to get a solid footing and exert st
running on the belt, it is best to stop the engine and m
belt on the pulley as far as possible. Then take a sm
double it, slip one end through the arms and around the
rim of the pulley, and the other end through the loop f
the double of the rope; then stand on the floor on the

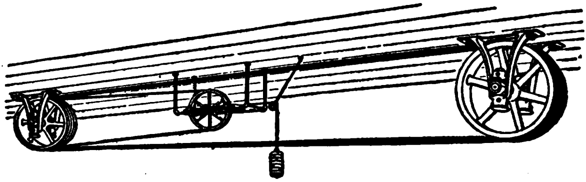
side, and draw on the rope, when the belt will be hugged to the periphery of the pulley. When motion is communicated, it may be slipped on without any trouble, while by letting go the end of the rope when the belt is on the pulley, the noose will be undone and the rope thrown off.

Rule *for finding the required size of a driving-pulley for any required speed.*—Multiply the diameter of the driven pulley by the number of revolutions it should make, and divide the product by the revolutions of the driver. The quotient will be the required size of driver.

Rule *for finding the diameter of a driven pulley for a given number of revolutions, the diameter and revolutions of the driver being known.*—Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven pulley. The quotient will give the proper size of the driven pulley.

Rope Driving.—The use of rope made of cotton or manilla is being very largely extended where it is desired to transmit power to considerable distances. The cost of rope is much less than that of belting, and moreover the pulleys do not have to be lined up so accurately when rope is used.

The pulleys used are grooved, usually V-shaped and at an angle of 30° to 60°, the practice of engineers varying in this respect. Some engineers also use a curved groove. The sides of the grooves, whatever may be their form, must be perfectly smooth and polished so as to avoid cutting the rope fibres. The diameters of the pulleys must be properly chosen with reference to the diameter of the rope, for to attempt to carry a large and stiff rope around a pulley of small diameter would result in the rapid wearing of the rope. There are two general methods of using ropes where it is desired to use several working side by side on the grooves of the same pulley. One is to put them on like so many spliced belts, one working in each groove. The difficulty experienced in this method of working is that they do not all pul equally, and this is especially the case when driving from a lar to a small pulley. It may be largely overcome by making the grooves of the smaller pulley with a sharper angle. The other method is to wrap the rope around the pulleys as many times as there are grooves, and then carry it through idlers so arranged as to allow the tension to be varied, and then carrying back to the starting-point and splicing it. This method is shown clearly in the figure.



ROPE TRANSMISSION.
"Wound System." With Take-Up.

Idlers whenever used should be arranged, if possible, so that the rope will always be bent in one direction, as changing the direction of bending greatly increases the wear.

The speeds allowable vary from about 25 to 100 feet per second, with perhaps the most common practice at about 80 feet per second. The tension on the rope is made up of three separate tensions: 1st, the initial tension when not in motion; 2d, that due to centrifugal force; 3d, that necessary to transmit the power. The sum of all these must not be allowed to exceed the safe working strength of the rope. The following tables give the breaking weight of various sizes, and also what would be considered the safe weight if they were used to support a weight, not being in motion in any way. This safe load is taken at one-quarter of the breaking load. For rope driving, however, a much greater factor of safety must be used, and the safe working strength for rope driving will be taken at about one-eighth of the safe load T when at rest, or one-thirty-second of the breaking load S. *The tables also* give the smallest allowable diameter of pulley *for each size rope.*

ROPES.

Hemp Ropes, White. Three Strands.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
21.	6 in.	17.1	324000	81000	9 4	.1064
19.	5½	15.7	272000	68000	7.9	.1266
16.5	5 in.	14.25	225000	56250	6.52	.1533
14.	4½	12.1	182000	45500	5.28	.1894
12.	4 in.	11.4	144000	36000	4.18	.2392
11.	3¾	10.7	126000	31500	3.67	.2725
10.	3½	10.	110000	27500	3.2	.3125
9.	3¼	9.27	95000	23750	2.76	.3613
8.	3 in.	8.57	81000	20250	2.35	.4255
7.	2¾	7.85	68000	17000	1.97	.5076
6.	2½	7.14	56200	14050	1.63	.6135
5.25	2¼	6.43	45500	11375	1.32	.7575
4.25	2 in.	5.70	36000	9000	1.04	.9615
3.4	1¾	5.00	27500	6875	0.80	1.25
2.75	1½	4.28	20200	5050	0.588	1.700
2.1	1¼	3.97	14000	3500	0.407	2.457
1.5	1 in.	2.86	9000	2250	0.261	3.831
1.22	⅞	2.5	6900	1725	0.200	5.000
0.97	¾	2.14	5050	1262	0.147	6.803
0.74	⅝	1.78	3500	875	0.102	9.803
0.53	½	1.43	2240	560	0.065	15.38
0.34	⅜	1.07	1260	315	0 036	27.77
0.18	¼	0.71	560	140	0.016	62.5

Manilla Ropes. Three Strands.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
26.4	6 in.	17.1	216000	54000	8.64	.1157
23.2	5½	15.7	181500	45375	7.26	.1377
20.	5 in.	14.25	150000	37500	6.00	.1666
17.2	4½	12.1	121000	30250	4.86	.2057
14.4	4 in.	11.4	96000	24000	3.84	.2604
13.	3¾	10.7	84400	21100	3.38	.2958
11.8	3½	10.	73600	18400	2.94	.3401
10.5	3¼	9.27	63500	15875	2.53	.3952
9.35	3 in.	8.57	54000	13500	2.16	.4629
8.2	2¾	7.85	45400	11350	1.81	.5524
7.1	2½	7.14	37500	9375	1.5	.6666
6.	2¼	6.43	30400	7600	1.21	.8264
5.	2 in	5.70	24000	6000	0.96	1.041
4.	1¾	5.00	18400	4600	0.725	1.379
3.3	1½	4.28	13500	3350	0 54	1.852
2.5	1¼	3.57	9380	2345	0.375	2.666
1.8	1 in.	2.86	6000	1500	0.24	4.166
1.46	⅞	2.5	4600	1150	0.184	5.435
1.17	¾	2.14	3380	845	0.135	7.407
0.89	⅝	1.78	2350	587	0.093	10.75
0.63	½	1.43	1500	375	0.060	16.66
0.41	⅜	1.07	845	211	0.033	30.30
0.22	¼	0.71	375	93	0.015	66.66

ROPES.

Tarred Hemp Ropes. Four Strands.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
36.	6 in.	18 in.	230000	57500	15.1	.0662
32.	5½	16½	194000	48500	12.7	.0784
28.	5 in.	15 in.	160000	40000	10.5	.0952
24.	4½	13½	130000	32500	8.52	.1174
20.	4 in.	12 in.	102500	25625	6.72	.1488
18.	3¾	11¼	90000	22500	5.92	.1689
16.	3½	10½	78500	19625	5.16	.1938
14.6	3¼	9¾	67700	16925	4.44	.2252
12.9	3 in.	9 in.	57700	14425	3.78	.2645
11.4	2¾	8¼	48400	12100	3.18	.3144
9.9	2½	7½	40000	10000	2.63	.3802
8.4	2¼	6¾	32400	8100	2.13	.4695
7.	2 in.	6 in.	25600	6400	1.68	.5952
5.8	1¾	5¼	19600	4900	1.29	.7752
4.6	1½	4½	14400	3600	0.945	1.058
3.5	1¼	3¾	10000	2500	0.656	1.524
2.5	1 in.	3 in.	6400	1600	0.420	2.381
2.	⅞	2⅝	4900	1225	0.322	3.105
1.6	¾	2¼	3600	900	0.236	4.237
1.2	⅝	1⅞	2500	625	0.164	6.097
0.9	½	1½	1600	400	0.105	9.523
0.58	⅜	1⅛	900	225	0.059	16.95
0.31	¼	¾	400	100	0.026	38.46

Cotton Ropes. Three Strands of Fine Yarns.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
14.7	6 in.	18 in.	18000	4500	7.2	0.1389
12.9	5½	16½	15125	3781	6.05	0.1653
11.2	5 in.	15 in.	12500	3125	5.00	0.2000
9.5	4½	13½	10125	2531	4.05	0.2469
8.0	4 in.	12 in.	8000	2000	3.20	0.3125
7.2	3¾	11¼	7030	1782	2.81	0.3559
6.5	3½	10½	6125	1531	2.45	0.4082
5.8	3¼	9¾	5281	1320	2.11	0.4739
5.2	3 in.	9 in.	4500	1125	1.80	0.5555
4.5	2¾	8¼	3781	945	1.52	0.6579
4.	2½	7½	3125	781	1.25	0.8000
3.4	2¼	6¾	2531	633	1.01	0.9901
2.8	2 in.	6 in.	2000	500	0.80	1.250
2.3	1¾	5¼	1531	383	0.61	1.639
1.8	1½	4½	1125	281	0.45	2.222
1.4	1¼	3¾	781	195	0.31	3.226
1 ft.	1 in.	3 in.	500	125	0.20	5.000
0.82	⅞	2⅝	383	96	0.15	6.666
0.65	¾	2¼	281	70	0.11	9.009
0.5	⅝	1⅞	195	49	0.078	12.82
0.35	½	1½	125	31	0.05	20.00
0.23	⅜	1⅛	70	17	0.028	35.71
0.125	¼	¾	31	8	0.012	83.33

The following tables give the horse power transmitted safely, cording to the formulæ of Mr. C. W. Hunt, of New York; also e sag of rope between pulleys:

Horse-power of Transmission Rope at Various Speeds.
Computed from formula (2), given above.

Diam. of Ropes.	Speed of the Rope in feet per minute.											Smallest Diam. of Pulleys in inches.
	1500	2000	2500	3000	3500	4000	4500	5000	6000	7000	8000	
½	1 45	1.9	2.3	2.7	3	3.2	3.4	3.4	3.1	2.2	0	20
⅝	2 3	3.2	3.6	4.2	4.6	5.0	5.3	5.3	4.9	3.4	0	24
¾	3.3	4.3	5 2	5.8	6.7	7.2	7 7	7.7	7.1	4 9	0	30
⅞	4.5	5.9	7.0	8.2	9.1	9.8	10.8	10 8	9.3	6 9	0	36
1	5.8	7 7	9.2	10.7	11.9	12 8	13.6	13 7	12.5	8.8	0	42
1¼	9.2	12.1	14.3	16.8	18.6	20.0	21.2	21.4	19.5	13.8	0	54
1½	13.1	17.4	20.7	23 1	26.8	28.8	30 6	30.8	28.2	19.8	0	60
1¾	18	23.7	28.2	32.8	36.4	39.2	41.5	41.8	37 4	27.6	0	72
2	23.2	30.8	36.8	42.8	47.6	51.2	54.4	54 8	50	35 2	0	84

Sag of the Rope between Pulleys.

Distance between Pulleys in feet.	Driving Side.	Slack Side of Rope.		
	All Speeds.	80 ft. per sec.	60 ft. per sec.	40 ft. per sec.
40	0 feet 4 inches	0 feet 7 inches	0 feet 9 inches	0 feet 11 inches
60	0 " 10 "	1 " 5 "	1 " 8 "	1 " 11 "
80	1 " 5 "	2 " 4 "	2 " 10 "	3 " 8 "
100	2 " 0 "	3 " 8 "	4 " 5 "	5 " 2 "
120	2 " 11 "	5 " 8 "	6 " 3 "	7 " 4 "
140	3 " 10 "	7 " 2 "	8 " 9 "	9 " 9 "
160	5 " 1 "	9 " 3 "	11 " 3 "	14 " 0 "

Gearing.—If on two parallel shafts we mount two pulleys of ch diameter that their faces just touch, we can by turning one aft drive the other through friction. The surfaces of the pul-y faces are not smooth, and, if looked at under the microscope, ill be found to be made up of alternate hills and valleys, and it by the pushing of a hill on one pulley against an adjacent hill the other pulley that the motion is transmitted. The pulleys ay be considered then as gear wheels having an infinite number f teeth meshing into each other. Suppose that we cut larger eth, making larger alternate elevations above and depressions eneath the *cylindrical surface of* the pulley face, along which *rface we supposed the two* pulleys first touched. The tooth of eel will fit into the space of the other, and the origi rical surface will have disappeared. It is, however, stil lered to exist, and is called the *pitch surface.* The diamet is cylinder is called the *pitch diameter.* The *pitch* of a ge l is the distance measured along this pitch circle or surfac one side of a tooth to the same side of the next tooth. Th h is divided into two parts: the *thickness,* which is the width o tooth, and the *space.* The space is a little wider than th th, and the difference between the two is called the *backla* cut gears this difference is very small indeed. Only gears o e same pitch will work together, and when they have the sa itch the number of teeth is proportional to their diameters.

Spur Gears are used to connect shafts which are parallel ach other.

Bevel Gears are employed where the shafts are at an ang with each other. With bevel gears the pitch is measured at th larger end of the tooth.

Kinds of Teeth.—There are two forms in common use, call the *cycloïd* and the *involute,* the latter being employed where th number of teeth is small. Two wheels to be geared together mu have not only the same pitch, but also the same tooth form.

Rule *for finding the diameter of toothed wheels.*—Multiply th number of teeth by the number of thirty-seconds of an inch co tained in the pitch: the product will be the diameter in tenths an hundredths of an inch; or, multiply the number of teeth by th true pitch, and the product by ·3184. These results give only th diameter between the pitch-line, on one side, and the same line o the other side, and not the entire diameter from point to point o teeth on opposite sides. It must also be borne in mind that the results are only approximate diameters, since the wheel often vari from the computed diameter in consequence of shrinkage and oth causes.

Rule *for finding the required number of teeth in a pinion to hav ny given velocity.*—Multiply the velocity or number of revolutio the driver by its number of teeth or its diameter, and div e product by the desired number of revolutions of the pinion or riven.

Rule *for finding the diameter of a pinion, when the diameter of* e *driver and the number of teeth in driver and pinion are given.*—ultiply the diameter of the driver by the number of teeth in the inion, and divide the product by the number of teeth in the driver, d the quotient will be the diameter of pinion.

Rule *for finding the number of revolutions of a pinion or driven, en the number of revolutions of driver and the diameter or the mber of teeth of driver and driven are given.*—Multiply the mber of revolutions of driver by its number of teeth or its ameter, and divide the product by the number of teeth or the ameter of the driven.

Rule *for finding the number of revolutions of a driver, when the olutions of driven and teeth, or diameter of driver and driven, are en.*—Multiply the number of teeth or the diameter of driven y its revolutions, and divide the product by the number of teeth the diameter of driver.

Rule *for finding the number of revolutions of the last wheel at the d of a train of spur-wheels, all of which are in a line, and mesh o one another, when the revolutions of the first wheel, and the mber of teeth, or the diameter of the first and last are given.*—ltiply the revolutions of first wheel by its number of teeth or diameter, and divide the product by the number of teeth or diameter of the last wheel; the result is its number of revo- ions.

Rule *for finding the number of revolutions in each wheel for a train pur-wheels, each to have a given velocity.*—Multiply the number revolutions of the driving-wheel by its number of teeth, and ide the product by the number of revolutions each wheel is to ke. The result will be the number of teeth required for ch.

Rule *for finding the number of revolutions of the last wheel in a of wheels and pinions, spurs or bevels, when the revolutions of rst or driver, and the diameter, the teeth or the circumference of* *all the drivers and pinions, are given.*—Multiply the diameter, th circumference, or the number of teeth of all the driving-whe together, and this continued product by the number of revoluti of the first wheel; and divide this product by the continued pro uct of the diameter, the circumference, or the number of teeth o all the pinions, and the quotient will be the number of revoluti of the last wheel. In this case each wheel has mounted on th same shaft with it a pinion which meshes with the next wheel o the train.

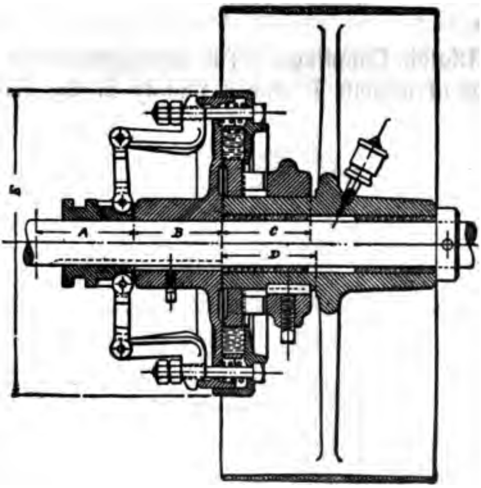
Friction Connections are used principally for two purposes to take the place of a tight and loose pulley, in which case th arrangement is called a *Friction Clutch Pulley*, or to arrange tw or more sections of a line of shafting so that the sections may b disconnected from each other or reconnected without stopping th shaft. In this latter case the arrangement is called a *Clut Coupling.*

The General Principles of most of the different makes o Clutches are alike. A pulley is mounted on a sleeve in which th shaft turns, and is free to turn on it. The pulley has a speci rim attached to the arms or a disk attached to the hub, which i gripped between the jaws of the Clutch device. The Clutch i mounted on and keyed to the shaft. The jaws are made to op or shut by moving the Clutch Collar in one direction or anoth along the shaft by a fork handle. This operates some kind o a toggle joint and moves the jaws.

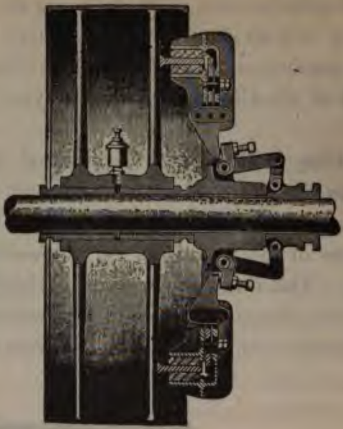
The Moore & White Clutch Pulley is shown in the figure an is constructed as follows:

The pulley is made with a long hub to give sufficient wearin surface. The hub on one side is turned true to receive the Clutc Upon the hub of the pulley is keyed a collar with Lugs on on side which engage with Lugs on the Friction Disc; this cau the Disc, that fits loosely on the hub of the pulley, to revolve w the pulley, and at the same times leaves the Disc free to vib sideways if necessary. The advantage of the Disc being loos connected witn the pulley in this manner will be appreciated pulley should become worn loose on the shaft, or in case t or pulley or hub should not run true; this prevents the ı surface wearing when the Clutch is disengaged; it also s the part of the Clutch which is keyed to the shaft from g loose.

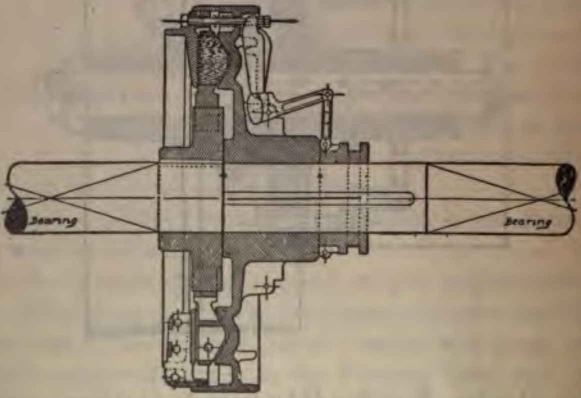
Friction Disc is filled with hard wood, and presents two ıin wood surfaces which come in contact with the two iron s. The two iron surfaces are drawn in contact with the ood surfaces of the Disc by a very powerful mechanism, as in the cut. The Draw Bolts are provided with Jam Nuts, an be easily adjusted to take up any wear that may occur. riction Clutch can be made in halves, applied to Wood , Gearing, Sprocket Wheels, or to anything special that desired.



Hill Clutch is shown clearly in the accompanying figure, eds no further description.



Cut-off Clutch Couplings.—The arrangement for connecti two sections of a shaft is shown plainly in the accompanyi figure.



Another cut shows the friction clutch pulley, shaft, and t *lever form of* clutch shifter. The shifter may also be operat *by a wheel* and spur-gear or wheel and worm-gear.

eumatic transmission of power has many important appli-
ıs, and is coming into extensive use for operating cranes,
, drills, riveting machines, coal-mining machinery, railroad
ls, shop tools, sand-blasts, brakes, etc. It is also used for
ing carpets and railroad car cushions, refrigerating, pump-
unnelling, and for carrying messages or packages through
. Some pneumatic locomotives are in use for operating
cars, while for driving cars in mines they are quite com-
The most extensive installations are to be found in Paris,
e one central station is laid out for 24,000 H.P., and supplies
hundreds of motors of sizes from ⅛ H.P. to 50 H.P., the
eing compressed to about six atmospheres.

e compressors are pumps driven by belt or gear-wheels, or
lirectly driven by a water-wheel (by means of a crank), or
steam-cylinder and piston. In this last case, which is the
common, the air-piston and steam-piston are mounted on the
nds of the same piston-rod. On the steam end steam is ad-
d at its maximum pressure, and is allowed to expand till it
es a low pressure at the end of the stroke. The reverse
place in the air-cylinder. Here air is admitted at atmo-
ic pressure and fills the cylinder. On the return stroke the
ure gradually increases, till at the end of the stroke the press-
ises to that *of the reservoir into* which it is pumping. From
can be seen that when the steam-pressure is least, the air-

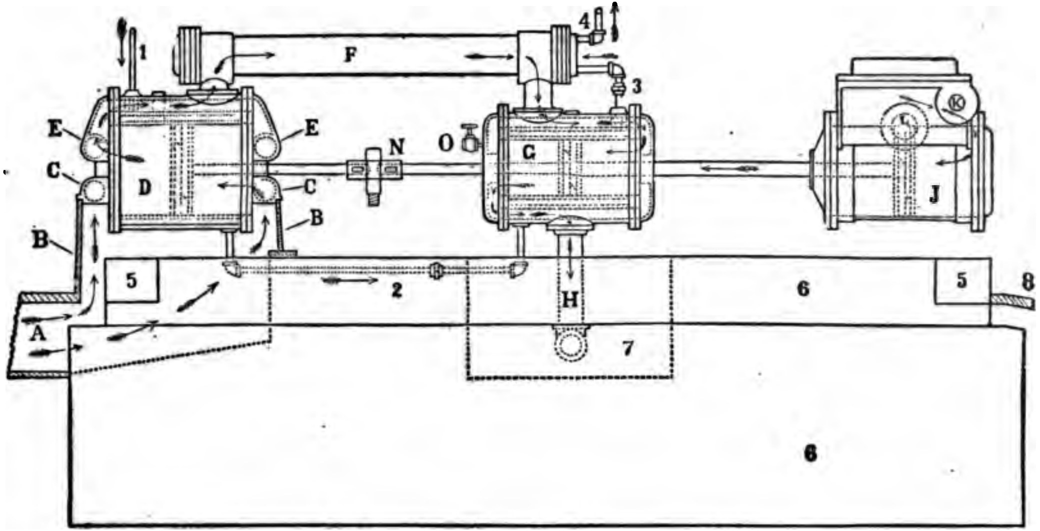
pressure against which it is working is greatest; and, therefore, very heavy fly-wheels have to be used to store up the surplus energy at the first part of the stroke and to give it out on the last part. To equalize more nearly the work at different parts of the stroke, the compression may be divided into two stages by using a large cylinder for performing the first part, say, from atmospheric to 30 pounds, and a smaller cylinder for finishing the compression.

The compound air compressor is the name given to such an arrangement from its resemblance to the compound engine. In addition to equalizing the strains on the machine, it also is much more efficient—*i. e.*, compresses a given amount of air with a less amount of steam used in the steam-cylinder. For very high pressures, as for 2000 pounds per sq. in., the compression is divided into three or even four stages by using three or four air-cylinders as the case may be. The steam end is also made compound or triple expansion to secure the greatest economy in the use of steam. Of course, where two steam-cylinders are used they may cross compound or tandem, and the same is true of the air-cylinders. The Rand Drill Co. use the cross compound, while the Norwalk Iron Works Co. use the tandem arrangement.

The cut shows a single steam-cylinder and a tandem compound air compressor with names of the different parts of the machine.

The Intercooler.—When air is compressed its temperature rises to an extent depending on the amount of compression and the original temperature at which the air was taken in. The rise in temperature is shown in the following table:

Temperature of air before compression,	60°	90°
Temperature of air compressed to 15 lbs.	177°	212°
" " " 30 "	255°	294°
" " " 45 "	317°	362°
" " " 60 "	369°	417°
" " " 75 "	416°	465°
" " " 90 "	455°	507°
" " " 105 "	490°	545°
" " " 120 "	524°	580°



Arrows on the water pipes show the direction of water circulation. When pistons move as indicated by the arrow on the piston rod, steam and air circulate in direction shown by arrows in the cylinders.

A—Inlet Conduit for Cold Air.
B—Removable Hoods of Wood.
H—Discharge Air Pipe.
J—Steam Cylinder
1—Cold Water Pipe to Cooling Jacket.
2 & 3—Water Pipes

This rise in temperature has two bad effects: it makes lubricati difficult, and it increases the power necessary to compress a c tain number of cubic feet of air per minute to a certain numb of pounds pressure. To overcome this difficulty both cylinders a water-jacketed, which obviates it to some extent; but most of t cooling is done in the intercooler, which receives the air from t first cylinder. This intercooler is a tank through which runs large coil of small pipe carrying cold water. The heated co pressed air comes into contact with the extensive cooling surfa of the pipes, and after giving up its heat passes on to the seco cylinder. By thus cooling the air about 15 per cent. less pow is needed for the compression, 10 per cent. approximately bei saved by the intercooler, and the other 5 per cent. by the wat jackets of the two cylinders.

Volumes, Mean Pressures per Stroke, Temperatures, etc., in the Operation of Air-compression from 1 Atmosphere and 60° Fahr. (F. Richards, *Am. Mach.*, March 30, 1893.)

Gauge-pressure.	Atmospheres.	Volume with Air at Constant Temp.	Volume with Air not cooled.	Mean Pressure per Stroke; Air Constant Temp.	Mean Pressure per Stroke; Air not cooled.	Temp. of Air; not cooled.
1	2	3	4	5	6	7
0	1	1	1	0	0	60°
1	1.068	9363	.95	.96	.975	71
2	1.136	.8803	.91	1.87	1.91	80.4
3	1.204	.8305	.876	2.72	2.8	88.9
4	1.272	.7861	.84	3.53	3.07	98
5	1.34	.7462	.81	4.3	4.5	106
10	1.68	.5952	.69	7.62	8.27	145
15	2.02	.495	.606	10.33	11.51	178
20	2.36	.4237	.543	12.62	14.4	207
25	2.7	.3703	.494	14.59	17.01	234
30	3.04	3289	.4538	16.34	19.4	252
35	3.381	.2957	.42	17.92	21.6	281
40	3.721	.2687	.396	19.32	23.66	302
45	4.061	.2462	.37	20.57	25.59	321
50	4.401	.2272	.35	21.69	27.69	339
55	4.741	.2109	.331	22.76	29.11	357
60	5.081	.1968	.3144	23.78	30.75	375
65	5.422	.1844	.301	24.75	32.32	389
70	5.762	.1735	.288	25.67	33.88	405
75	6.102	.1639	.276	26.55	35.27	420
80	6.442	.1552	.266	27.33	36.64	432
85	6.782	.1474	.2566	28.16	37.94	447
90	7.122	.1404	.248	28.89	39.18	459
95	7.462	.134	.24	29.57	40.4	472
100	7.802	.1281	.2324	30.21	41.6	485
105	8.142	.1228	.2254	30.81	42.78	496
110	8.483	.1178	.2189	31.39	43.91	507
115	8.823	.1133	.2129	31.98	44.98	518
120	9.163	.1091	.2078	32.54	46.04	529
125	9.503	.1052	.2020	33.07	47.06	540
130	9.843	.1015	.1969	33.57	48.1	550
135	10.183	.0981	.1922	34.05	49.1	560
140	10.523	.095	.1878	34.67	50.02	570
145	10.864	.0921	.1837	35.09	51.	580
150	11.204	.0892	.1796	35.48	51.89	589
160	11.88	.0841	.1722	36.29	53.65	607
170	12.56	.0796	.1657	37.2	55.39	624
180	13.24	.0755	.1595	37.96	57.01	640
190	13.93	.0718	.154	38.68	58.57	657
200	14.61	.0685	.149	39.42	60.14	67

The following table, taken from Kent's Hand-book, will be found seful in determining the power required for various cases.

Horse-power required to compress and deliver one cubic foot of Free Air per minute to a given pressure with no cooling of the air during the compression; also the horse-power required, supposing the air to be maintained at constant temperature during the compresion.

Gauge-pressure.	Air not cooled.	Air constant temperature.
5	.0196	.0188
10	.0361	.0333
20	.0628	.0551
30	.0846	.0713
40	.1032	.0843
50	.1195	.0946
60	.1342	.1036
70	.1476	.1120
80	.1599	.1195
90	.1710	.1261
100	.1815	.1318

Horse-power required to compress and deliver one cubic foot of Compressed Air per minute at a given pressure with no cooling of the air during the compression; also the horse-power required, supposing the air to be maintained at constant temperature during the compression.

Gauge-pressure.	Air not cooled.	Air constant temperature.
5	.0268	.0251
10	.0606	.0559
20	.1488	.1300
30	.2578	.2168
40	.3842	.3138
50	.5261	.4166
60	.6818	.5266
70	.8508	.6456
80	1.0302	.7700
90	1.2177	.8979
100	1.4171	1.0291

The horse-power given above is the theoretical power, no allowance being made for friction of the compressor or other losses, which may amount to 10 per cent or more.

Capacity of Compressors: Norwalk Iron Works Co.—List of standard steam-driven compressors; 10 per cent. should be deducted from the theoretical capacity given in table for losses in friction, heating, etc.

Diameter of Air-cylinder.	Length of Stroke.	Diameter of Compressing Cylinder.	Diameter of Steam-cylinder.	Revolutions or Double Strokes per Minute.	Capacity Cubic Feet per Minute.	Steam Pipe.	Exhaust Pipe.	Air Pipe.	Water Pipe.	Horse Power.
8	10	5	8	200	116	2	2½	2	½	15
10	12	6¾	10	180	195	2½	3	2½	¾	28
14	16	9½	14	150	427	3	4	4	1	55
16	16	9½	16	150	558	3	4	4	1	80
20	24	13½	20	110	960	5	6	5	1¼	125
22	24	13½	22	110	1160	5	6	5	1¼	150
26	30	17½	24	90	1659	6	8	6	1¼	215
28	30	17½	28	90	1924	8	10	6	1¼	250
32	36	21½	30	80	2686	8	10	8	1½	350

Capacity at high altitudes is less than at sea-level. Multiply the figures given above by the percentages in the following tal to get the capacity at different heights.

Height above sea =	1000	2000	3000	4000	5000
Per cent...............	97	94	91	89	86

Regulation of pressure is obtained by cutting off the supply steam to the steam-cylinder when the pressure gets too high, a thus slowing down the engine to the slowest speed at which it w pass the dead centres, and reversing the operation when the pre ure is too low. To do this a balanced valve is placed in the stea supply-pipe, which valve is attached to a piston that works a little cylinder to which leads a pipe from the air-reservoir. small safety-valve, which can be adjusted to blow at any pressu is placed in this pipe, so that when the pressure rises beyond t point it blows and lets air into the little air-cylinder, thus drivi up the piston and closing the steam-valve. The piston would driven to the top of the cylinder, thus shutting off the stea supply at once, were it not that a fine slot cut in the cylin is uncovered as the little piston rises, and thus lets out the a the engine having a part only of the steam shut off. If the pre ure in the air-receiver rises still higher, the little piston ri accordingly and the engine is still farther slowed down. If air is being used from the reservoir, the main safety-valve on t reservoir, which is set a couple of pounds higher than the lit pressure-regulating valve, will blow and relieve the pressure the reservoir.

Reservoirs or receivers are steel tanks of a strength suffici to stand the pressures to be used, which are placed one near t compressor and one near the point where the compressed air is be used. They are, or should be, provided with a man-hole cleaning and for drawing off any water that may collect in the They perform several important purposes, viz.:

They may, if large enough, act to store power; but usually, *cept with pneumatic* locomotives, they are not made of suffici *size to store any* considerable amount. The one near the c

serves to take up its pulsations, and the pipe-system thus
ir at a constant pressure instead of a fluctuating one. The
r near the air-motors supplies sudden demands without the
e dropping appreciably, and thus prevents fluctuations of
the pipe line. Both, therefore, tend to promote a steady
the pipe line at a uniform pressure and velocity, and thus
the loss of pressure by friction in the pipe line to a minimum.
' also allow any water which may be in the compressed air
rate and escape from it. While the best size of receiver to
l depends upon the special conditions of each case, the following
list shows the sizes commonly used with the compressors in
:ceding table:

Diameter.	Length.	Size pipe.
24 inches.	4 feet.	2½ inches.
30 "	5 "	4 "
36 "	8 "	5 "
36 "	13 "	6 "
42 "	16 "	8 "

pipe line is one of the most important parts of a com-
l air-system of power transmission, and the size of the pipe
)e carefully determined. If it is too large, money will be
; if it is too small, there will be great loss of pressure
to friction. Pressure and power are lost by friction just as
er-pipe, but whereas in hydraulics the lost power bears the
)roportion to the total power as does the loss of pressure or
,o the total pressure, this is not the case with compressed
e loss in power being less in proportion than the loss in
The loss in pressure for a pipe 2000 feet long is practically
the loss for the same diameter pipe 1000 feet in length;
, the loss in pressure varies proportionally with the length.
send in one case 100 cu. ft. per minute through a pipe, and
ther case 200 cu. ft. through the same pipe, the loss of press-
the *second case will be 4 times* that in the first. That is,
ıg the velocity gives 4 times the friction loss,

In remote portions of a mine it is of interest to know th tities of air that will flow through small pipes, when the p is drawn down from a large main which furnishes a supply stant pressure. Below we give such a table:

Flow of Compressed Air Through Pipes.

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Nominal Size of Pipe ☞	1 in.		1¼ in.		1½ in		2 in.		2½ in.	
Length of Pipe in Feet ☞	50	100	100	300	100	300	200	500	250	600
UNIFORM PRESSURE AT THE ENTRANCE OF THE PIPE EIGHTY POUNDS GAUGE. VARIOUS PRESSURES AT THE POINT OF DELIVERY										
79.8	23.2	16.4	35.2	20.3	63.6	36.7	84.7	53.6	142.0	91.7
79.6	33.1	23.4	49.7	28.7	89.9	51.9	119.6	75.7	200.9	129.6
79.4	40.4	28.6	61.0	35.2	109.1	63.0	146.5	92.7	244.4	157.7
79.2	46.8	33.1	70.3	40.6	127.1	73.4	169.1	107.1	283.2	183.1
79.0	52.3	37.0	78.6	45.4	142.0	82.0	189.1	119.7	317.1	204.6
78.8	57.1	40.4	86.1	49.7	155.4	89.7	207.0	131.0	348.4	224.8
78.6	61.6	43.6	93.0	53.7	168.0	97.0	223.3	141.3	377.0	243.9
78.4	65.9	46.6	99.2	57.3	179.3	103.5	238.7	151.1	399.6	258.4
78.2	70.8	49.7	105.4	60.8	190.5	110.0	252.9	160.1	424.1	273.6
78.0	73.7	52.1	110.8	64.0	200.7	115.9	266.5	168.7	446.7	288.6
77.8	77.2	54.6	116.2	67.1	209.9	121.2	279.2	176.7	469.0	302.6
77.6	80.7	57.1	121.4	70.1	219.1	126.5	291.5	184.5	489.6	315.9
77.4	84.0	59.4	126.3	72.9	228.1	131.7	303.4	192.0	509.3	328.6
77.2	87.1	61.6	131.1	75.7	236.7	136.6	314.4	199.0	528.3	340.8
77.0	90.3	63.7	135.4	78.2	245.2	141.6	325.5	206.0	546.5	352.6
76.8	92.9	65.7	139.8	80.7	252.4	145.7	336.1	212.7	564.2	364.0
76.6	95.6	67.7	143.9	83.1	259.8	150.0	346.2	219.1	581.3	375.0
76.4	98.4	69.6	148.1	85.5	267.6	154.5	356.0	225.3	597.5	385.5
76.2	101.0	71.5	152.1	87.8	274.7	158.7	365.6	231.4	613.8	396.0
76.0	103.8	73.4	156.1	90.1	281.3	162.4	375.6	237.3	629.3	406.0
75.8	106.3	75.2	159.7	92.2	288.4	166.6	383.9	243.0	644.5	415.8
75.6	108.7	76.9	163.3	94.3	295.5	170.6	392.8	248.6	659.2	425.3
75.4	111.0	78.5	167.0	96.4	301.7	174.2	401.4	254.0	673.8	434.7
75.2	113.3	80.1	170.4	98.4	307.9	177.8	409.7	259.3	687.8	443.8
75.0	115.5	81.7	173.9	100.4	314.3	181.5	417.9	264.5	701.6	452.7

ELBOWS AND BENDS.

We give below an original table showing the effect of elbows. The friction as being equal to a certain length of straight pipe of same size. The friction of th pipe is given on page 60. An elbow with radius of half the diameter of the pipe i as can be made. The beneficial effect of even a little curve, in comparison witl sharp turn, is evident at a glance.

Radius of Elbow 5 diameters. Equivalent length of straight pipe 7.85 diam
" " 3 " " " " 8.24 "
" " 2 " " " " 9.03 "
" " 1½ " " " " 10.36 "
" " 1¼ " " " " 12.72 "
" " 1 " " " " 17.51 "
" " ¾ " " " " 35.09
" " ½ " " " " 121.20

Flow of Compressed Air Through Pipes.

Final Pressure at the Point of Delivery—80 lbs. Gauge.

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Cubic Feet of Free Air Delivered in Compressed Form at 80 lbs. Gauge Pressure, per Minute.

	Nominal Size of Pipe in Inches ☞	1		1¼		1½		2		2½		3		3½		4		4½		5		6		7		8	
	Length of Pipe in Feet ☞	50	100	100	300	250	500	250	750	250	750	500	1500	750	2000	1000	3000	1500	3000	2000	4000	2000	5000	3000	10000	3000	10000
Gauge Pressure at the Entrance to the Pipe.	80.2	23.7	16.8	35.6	20.7	40.1	28.4	76.0	49.0	143	83	163	95	210	128	263	153	288	211	383	271	558	352	694	379	999	546
	80.4	33.1	23.4	49.7	29.0	56.0	39.6	106.1	61 6	200	116	228	132	292	179	368	213	416	295	535	379	781	493	970	530	1397	763
	80.6	41.1	29.0	60.9	35.4	68.7	48.6	130.0	75.5	245	142	279	162	358	220	451	262	506	361	656	464	957	605	1189	650	1712	936
	80.8	47.0	33.2	70.3	41.0	79.3	56.0	150.1	87.1	283	164	322	187	420	254	521	302	589	417	757	536	1105	699	1373	750	1977	1080
	81.0	52.5	37.1	78.7	45.7	88.7	62.8	168.0	97.5	312	184	361	211	463	284	582	338	659	465	847	600	1236	780	1535	839	2210	1208
	81.2	57.5	40.7	86.2	50.1	97.3	68.8	184.2	107.0	348	202	397	229	507	311	642	370	721	511	930	658	1356	857	1685	921	2437	1326
	81.4	62.2	44.0	93.2	54.2	105.1	74.3	199.0	115.5	375	218	428	248	549	337	690	400	781	552	1004	711	1464	925	1819	994	2619	1431
	81.6	66.5	47.0	99.7	58.0	112.4	79.5	212.9	123.5	402	233	457	266	586	360	738	428	885	591	1074	760	1566	989	1946	1063	2802	1531
	81 8	70.6	50.0	105.8	61.5	119.3	84.4	225.8	131.0	426	247	485	282	622	381	783	454	886	627	1139	807	1662	1049	2063	1128	2974	1624
	82.0	74.4	52.6	111.5	65.0	125.8	88.9	238.1	138.2	449	261	512	297	657	402	826	479	934	661	1202	851	1753	1107	2178	1190	3136	1714
	82.2	78.1	55.2	117.5	68.3	132.0	93.4	250.0	145.1	472	274	537	312	689	422	867	503	1071	694	1262	894	1840	1162	2286	1249	3292	1799

To properly proportion the size of pipe for a transmission tem we must consider the cost of coal, compressors, and pipe, the pressure to be used, and to get the best results skilled j ment and experience are necessary. For small and simple in lations which are run usually at a pressure near 80 pounds, where the distances are comparatively short, the following ta taken from the catalogue of the Norwalk Iron Works Comp will be found useful. In the first table (page 63) the figures in first column, less 80, give the loss of pressure due to friction. T with a 1 inch pipe we can transmit 55.2 cubic feet per minute tance of 100 feet with a loss of 2.2 pounds, a very moderate If we should want to run 200 feet, the same pipe will give loss of about 4.4 pounds, which might be allowable for some while for others a larger pipe would be desirable.

Air Motors are of various types, from the reciprocating drill to the rotary engine type used in the Paris system, O nary steam engines can be used as air motors, and likewise ordi steam-driven pumps. The quantity of air used per horse-po varies with the size of units, as does the water consumption i steam engine. Moreover, this quantity can be very much les if just before the compressed air goes into the motor it be he to about 350° F., and the hot air used expansively. When heated the quantity of air used per horse-power hour is engines of ½ horse-power, with air at 80 pounds pressure, a 800 cubic feet. For an 80 horse-power engine under sim conditions a test showed a consumption of 465 cubic feet hour.

Efficiency of Compressed Air Systems.—There are losses the engine due to friction, losses in the compressor due to frict and heating, losses in the pipe line due to friction, losses in valv etc., and losses in the motor. The efficiency of the engine a compressor may be taken at about 60 to 65 per cent., that of t pipe laid at from 95 to 98 per cent., and that of the motors fro *60 to 80 per cent.,* depending on the size. The combined efficien *of a complete system*—that is, the horse-power taken out of

rs divided by that put in at the compressors—may be taken
om 35 to 55 per cent.

ectric transmission of power is one of the most common
valuable methods in use at the present day. It is for long
nces the most efficient and least expensive in first cost. For
ium distances it is more flexible than shafting and belting
gearing, and except for very short distances it is displacing
e methods. For mining work, however, it is not so suitable
ompressed air, owing to the danger of explosion caused by
king at the motors. Like compressed air systems, it makes
of a generator or dynamo, which changes the mechanical
gy of a water-wheel or steam engine into the energy of the
tric current. The dynamo corresponds to the compressor and
orms a similar duty. Indeed it may be considered as an
trical pump, pumping electricity from a low pressure to a high
sure and tending to maintain between its terminals a practi-
y constant difference of electrical pressure. There is also a line
onveying energy from the generator to the point where it is
e used. In electric transmission this is, instead of a hollow
as with air, a solid copper wire, of size suitable for the power
e transmitted and for the distance. We have also the motors
changing the electrical energy back into mechanical energy,
ch is then used in driving tools. There are several different
es of motors specially adapted each to certain classes of work,
l these are described in the chapter on Electricity. Gener-
y speaking, however, it may be said that for distances between
erator and motors of less than 1500 feet direct current motors
used. If they are to be run in connection with a lighting sys-
, they must be of the same voltage as that system, which is
lly 110 volts, although the use of 220-volt lamps is becoming
e extensive. If the motors are to be supplied by an inde-
dent generator, it will be preferable to use a 220-volt system,
as to diminish the cost of the line. For very long distances,
to 1000 *to 1500 feet, it would* even be better to use a 500-volt
em.

Where we want to run at practically constant speed whatev the load on the motor, the shunt-wound motor will be used. If, for lathes, we want to have several speeds at which the motor wi run steadily, this is accomplished by a regulating rheostat or co troller. For planers or similar machines where there is durin the reversal a large rush of current a compound-wound moto with series coil aiding the shunt coil, is desirable. The seri motor is advisable only where the machine is constantly changin its speed, as in street-car work.

For greater distances higher pressures than 500 volts are use and alternate currents are used because of the ease with which may lower their pressure to a value not dangerous to human li when we get to the point where we want to use them—that is, th motor. In alternate current systems the current may be gen rated at a safe pressure of, say, 300 volts, raised in a transformer 5,000, 10,000 or even 15,000 volts, carried along a comparativel small wire at this pressure until near the motor, reduced another transformer to 300 volts and used at that pressure. transformers may be placed out of reach and require no attentio like motors and generators, the attendants are not subject to a greater danger than with the direct current systems.

The alternating current polyphase induction motor has prac cally the same characteristics as the direct current shunt mot and will be used in similar cases.

To determine the proper size of motor for driving a particular tool can best be done by taking a motor and ru ning the tool at its maximum speed and load, and with ampèremeter and voltmeter noting the volts and ampères. Mul ply the *largest* reading in ampères by the average reading of t voltmeter and divide the product by 750, or, to be more exact, 746. This gives the electrical horse-power delivered to the mot Divide this by the efficiency of the motor, which will vary fro 80 to 95 per cent., according to the size. This result gives t *rated horse-power* of the proper size motor.

Such experiments have been made on a large number of w different kinds by the authors and others, and the results of st importance will be found in an earlier part of this chapter der the heading, "Power Required for Machine Tools."

To calculate the line we must determine what electrical press-e we shall use, what power the motor will be, and what the lowable variation in the speed of the motor is between fully ded and running free. Suppose this variation is 8 per cent. e average motor has in itself a lack of regulation of about 3 r cent., so that the line should be large enough not to cause a riation of over 5 per cent. If the system were a 110-volts sys-m and the motor 5 horse-power, taking a current of about 40 pères we should use such a size wire that the loss of pressure s 5.5 volts when 4 ampères flowed through it. The method of lculating the size under such conditions is given in the chapter on ectricity and need not be repeated here. When several motors e supplied from the same line it frequently happens that they e never all working at full load at any one time. When this is e case the line need not be calculated large enough for the sum their horse-powers. The exact allowance to be made is not a atter concerning which any definite rule can be laid down. hen the number of tools is small, say 5 or 6, a deduction of 15 25 per cent. should be made. With 15 or 20 such tools as ose used in an ordinary machine-shop, measurements have own that a wire calculated for one-half the sum of the powers the separate tools was ample.

The gain in using high pressures is enormous. Suppose that . 10 B. & S. wire is used to connect motor and generator 500 t apart and 1 horse-power was being transmitted, the current at 0 volts being approximately 40 ampères. The loss in heating e wire would be about 7 per cent.

If we double the pressure, the loss will be ¼, or 1¾ per cent.

At 550 volts the loss would be $\frac{1}{25}$ of 7 per cent.

At 1100 " " " 100 of 7 "

we could transmit *with a 7 per cent.* loss 100 horse-power over *No. 10 wire if we used a pressure* of 1100 volts.

At 11,000 volts we could transmit 10,000 horse-power at 7 p cent. loss, or 100 horse-power 50,000 feet at 7 per cent. loss.

The size of generator is determined in a similar manner t that used in calculating the size of the line. While motors a rated in horse-power, generators are rated in kilo-watts, or K. W One K. W. = 1000 watts or 1000 volt-ampères = 1⅓ horse-pow If it is desired to select a generator to furnish current for o motor only of, say, 50 horse-power, the calculation is as follow 50 horse-power = 37½ K. W., the power delivered at the pulley o motor; 37.5 ÷ $\frac{90}{100}$ (the efficiency) = 41⅔ K. W., the electric power delivered to the motor terminals. Suppose we had a 5 p cent. loss on the line, then 41⅔ ÷ $\frac{95}{100}$ = 43.78 K. W., the size o generator. The nearest commercial size to this would be 45 K. W

Efficiency of electric transmission depends largely upon th size of units employed. The efficiency of dynamos and motors o the same sizes is practically the same, and approximate values a given in the following table. These efficiencies are the *commerci efficiencies*, namely power taken out of the machine ÷ power put i

H. P.	½	1	2	3	5	10	15	20	25	50	10
K. W.	½	1	2	3	4.5	8.7	12.7	16.7	20.7	40	8
Efficiency	70	80	81	82	85	87	89	90	91	93	9

The loss in the line may be made as small as desired by incre ing the size of wire and hence the cost. On account of regulati of pressure it rarely exceeds 10 per cent. except for very long di tances. It will be seen that the efficiency of motors and genera tors is considerably better than that of air compressors and a motors.

Lubricants.

To understand the quantity of oil required for steam-cylinde slide-valves, and the reciprocating or revolving parts of stea engines, we should first know what its objects are. The object o *oil is to diminish friction*, by interposing a thin film between th *sliding or revolving* surfaces. To insure perfect lubrication, urfaces must be kept coated at all times, under all pressures and velocities. In steam-engines there is a sliding and rotating friction, and it is very doubtful if any one kind of oil is perfectly suited to both. Oil has no tendency to improve the character of a bearing; its functions being simply to keep them apart, prevent heat, and diminish friction.

Temperature exerts a very important influence over any lubricant. A thin oil has a tendency to run off too fast, while a thick one is not sure to flow. Tallow, and all other thick and greasy compounds, are exposed to the same objection, as the bearing generally gets hot before the lubricant begins to flow. Besides, what may be called a good lubricant, one that adheres to the rubbing surfaces under ordinary circumstances, may not be equally well adapted to all conditions, as the area of the bearing surfaces varies with the size of the journals, and the form of the boxes, which causes a difference in the velocity of rotation. From this, it follows, that a lubricant that would be retained between the frictional surfaces under a light load, would be entirely pressed out under a heavy one.

The quantity of lubrication that the cylinders and slide-valves of any engine require, depends on the condition of the engine, the amount of work it is performing, and on the pressure and temperature of the steam. If the load is light, the pressure low, and the engine in good order, very little lubrication is necessary; but if the pressure and speed are high, and the engine is working up to its full capacity, the cylinder and valves will require to be frequently lubricated. But in no case should an unnecessary quantity be used, as it is likely to produce a greater evil than the one it was intended to remedy. A person having charge of steam machinery should understand the work each part has to perform, the speed at which it runs, and the weight it has to sustain. Crank-pins and main-bearings require to be frequently oiled; but the condition of the bearing will determine the quantity of lubrication needed. What *is needed in* any case is a few drops of good *oil applied often. It may be safely* said that five times the quantity of lubrication is used on the revolving and rubbing surfac and in the valves and cylinder of steam-engines, that is actuall necessary.

It is not by any means uncommon to see ignorant and inexperienced persons who have charge of steam-engines pouring oi on cross-head guides and piston-rods every five minutes durin the day. This oil is immediately rubbed off by the shoes or th piston-rod packing, without rendering any service, which is wilful waste of the necessary supplies in their charge, and has tendency to lessen the profits of the establishment.

As an example of what may be done in the saving of oil the following examples are given, taken from the Vacuum Oil Company reports, the oil used being their 600 W. cylinder oil:

Corliss compound, 20 and 33 × 48, 83 revolutions per minute, 1 drop of oil per minute.

Corliss triple expansion, 20, 33, and 46 × 48, 1 drop in minutes.

Porter-Allen compound, 20 and 36 × 36, 143 revolutions pe minute, 1 drop per minute.

Ball, 15 and 25 × 16, 240 revolutions per minute, 1 drop in 4 minutes.

Owing to the difference in the size of drops the actual quantit cannot be obtained from these figures.

On smaller engines, from 50 to 75 horse-power, one-half pint o good cylinder oil for 10 hours run is generally considered good An expert by watching his engine *constantly* and carefully ma diminish this considerably. A particularly good example wit which the authors are familiar is the case of an 11¼ × 14 Woodbury engine running at 265 revolutions, which uses one pint o the best cylinder oil, costing $1.00 per gallon, in 200 hours, th drops passing about once in four minutes. It is not advisable t try to bring the oil consumption down too low, for unless th engine be constantly watched the risk of serious damage far outweighs *the value of* the possible saving in oil.

On the crank-pin and the other parts of this engine a machi l costing 50 cents per gallon is used, the cups being set to npty in about two and one-half hours and dropping at the rate f 20 per minute. This oil is run through a filter and then used ver and over again. When a filter is used there is, of course, othing to be gained by trying to run with a very slow rate of ropping.

The requirements of a good lubricant are the following:

Body sufficient to keep the surfaces apart.

As fluid as possible consistent with this.

Smallest possible friction.

Freedom from all materials tending to corrode metal.

Freedom from "gumming."

A high flashing point.

Must remain fluid at the coldest temperature to which it will be ubjected.

Best lubricants for different purposes, as stated by Prof. Robert H. Thurston:

For very great pressures with slow speed, graphite, soapstone, allow, and greases.

For heavy pressures at slow speed, lard, tallow, and greases.

For heavy pressures at high speed, sperm, castor, and heavy nineral oils.

For light pressures at high speed, sperm, refined petroleum, live, rape, and cotton-seed oils.

For ordinary machinery, lard oil, tallow oil, and heavy mineral ils.

For steam cylinders, heavy mineral oils, lard, and tallow.

For watches and delicate mechanisms, clarified sperm, neat's-foot oil, porpoise, olive and light mineral oils.

Tests of Railway Master Mechanics' Association.—In these, 6 drops of oil were put into a dynamometer, which was run at 35 niles an hour, until the temperature was raised from 60° to 200° Fah. The exact number of revolutions necessary to produce this hange of temperature was *noted in* each case, and is given in the *ast column of the following table:*

Description of Oil.	Cost per Gallon.	Av Revo
Castor Oil	$1.25	12
Paraffine	.28	11
Mecca (black)	.45	9
Manufactured "*A*"	.35	9
" "*B*"	.90	9
" "*C*"	.25	9
Neat's-foot	.85	8
W. Virginia	.26	7
Sperm	1.75	7
Tallow	.70	7
No. 1 Lard	.70	7
Manufactured "*D*"	.25	6
" "*E*"	.85	6
" "*F*"	.20	6
W. Virginia (reduced)	.20	4
Grafton (treated)	.20	4

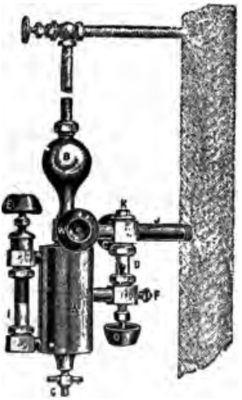
Lubricators of different patterns are made to serve the s requirements of an engine or of other machinery. In ge however, they should be "sight feed:" the oil being seen passes drop by drop. They should be readily adjustable feed, and so arranged that when once set the rate of flow w diminish as the oil runs out, and so that the jarring of mac will not alter the feed. The device for stoppi flow of oil altogether should be simple, and such that when it is opened again the same rate of flow will be given as before without touching the adjusting arrangement. The cup should also, of course, be made so that by no possibility can the jarring shake it to pieces.

Crank Oile

An ordinary sight feed oil cup, suitable for all parts of an engine, except crank-pin, cross-head, or cylinder, is shown in the figure.

k-pin oil cup which automatically shuts off the ı when the engine stops, is shown in the drawing. When the ıgine is at rest oil stands below the level of disk *J*, which con-ıins the hole through which oil feeds. As the engine speeds up ıe centrifugal force tends to throw oil up against the top of the up, and, therefore, a pressure is set up tending to force the il into the bearing. The higher the speed the greater the ıressure, and hence the greater the quantity forced into the bear-ng, which is just what is wanted, as the friction increases as the peed increases.

Cylinder lubricators are generally made so that the oil, drop y drop, is made to bubble up through water before passing into he steam-pipe leading to the steam-chest. n the cut, which shows one of the most ommon forms, *J* is the pipe through hich oil is fed to the main steam-pipe,) the valve for regulating the flow of il, *A* the oil-chamber, *I* the glass which ıows how much oil is in the chamber *A*, is a valve closing the pipe *J*, and *B* is condensation chamber in which col-cts condensed steam coming in from ıe upper pipe. Oil is put in through *E* hen *W* and *C* are closed. *F* and *G* are ow-off cocks for cleaning out the oil-ıamber and sight-feed tube. The ope-[illegible] is as follows: After the cham-ır has been filled with oil *C* is opened slowly, and when water ıs condensed so as to fill the sight-feed tube the valve *W* opened and the valve *D* adjusted to give the feed required. ıeam from the upper pipe, which extends almost to the bottom the oil-chamber, condenses and forms a water-column whose ıeight as well as the steam-pressure from *B* tends to force the oil ward. A bent pipe whose upper end is in the upper level of e oil has its lower *end leading into the* lower end of the sight-d *glass. Therefore, the pressure of* steam in the pipe J tend



to force the oil downward. The two steam-pressures are equal and opposite, but the weight of the water-column forces oil out through the sight-feed glass and into the steam-chest and thence to the cylinder.

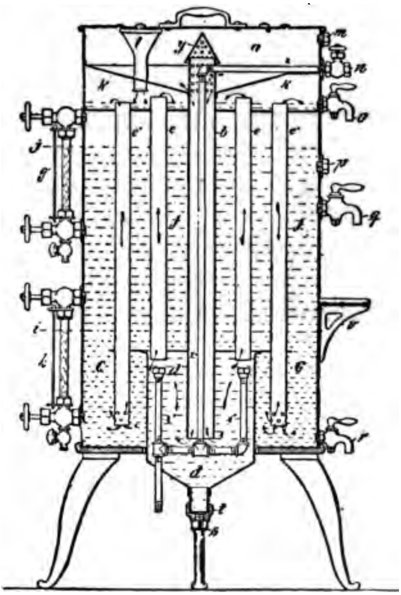
Oil filters are a necessary adjunct to any system of lubrication, and by their use the oil may be used several times over and a large amount of the oil bill saved. Of the many varieties one typical form is described and illustrated. In this filter the dirty oil to be purified is poured over the cone *y*, in receiver *a*, where coarse matter is arrested; it then passes down the large central tube *b* into the lower central compartment *d*, where it is submitted to a gentle heat by steam-pipes *x* and *x'* (these pipes have brass circulating tubes inside so as not to become hot-air bound), causing the molecules to separate and precipitate to the bottom the heavier residue matter, such as dirt or grit held in suspension.

The oil, after being thinned and lightened, passes up the tubes *e*; these tubes extend through the top of lower settling compartment a short distance to prevent particles lighter than oil, such as sawdust, waste, etc., from passing up, which might do great damage to machine bearings. The oil passing up overflows upon the bottom of the second settling compartment *k*, where it spreads out over a large area and permits a further settling, the upper strata of oil overflowing the tops of the tubes *e'*, which are slightly shorter than the inflowing ones.

The oil then passes down these tubes and out at the small holes or lower ends in small particles, being washed through the lukewarm water in space *c*, drop by drop, making the oil entirely clean and ready for use; it then passes above water line *i* into storage space *f*, where it accumulates for use. It is drawn off as needed through cock *q*, or may be conducted away by attaching pipe at screw-plug *p*.

New oil, when subjected to this process, is greatly benefited and is cleansed of all small particles of grit or dirt; new oil is put in at funnel *t*, attached to the bottom of receiver *a*. Water-gaug ates the height of oil in tank, and *h* the height of water in

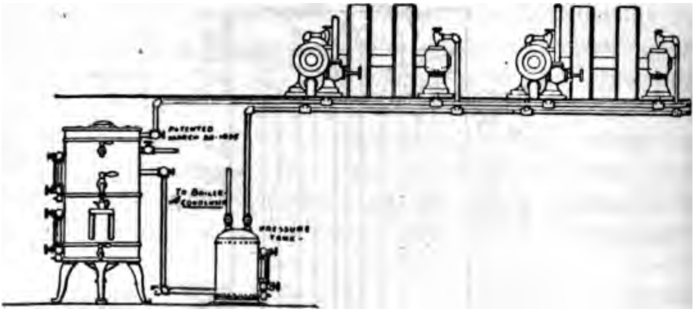
chanical filters are used, such as powdered cork, charcoal, ough which the oil is allowed to percolate, they should be that it is very easy to get at these substances for clean-



they get dirty quickly, and when dirty are of course of ner use in helping to clean the oil.

matic oiling return systems are coming into extensive use plants having many units. A pipe leads from a pressure ong near the bearings to be oiled, and into this main are small pipes running to the bearings. In each of these ipes is *a sight-feed. After* passing through the bearings *is collected into a return* main which runs to the filter.

After passing through the filter it runs to the pressure tank a is again forced through the oil pipes. Pressure is kept on t tank by a pipe leading to the boiler. Another arrangement with the oil purifier on a higher level than the bearings and wit the pressure tank used to force the dirty oil up into the filt The cut shows the first method.



Such an arrangement secures much more uniform lubricatio than with ordinary cups, and this with vastly less labor; in larg plants saving the services of one or more men.

Oil Separators.—Whenever the exhaust steam from an engin is used for heating it is advisable to make use of a device fo separating from the steam the oil coming from the cylinder. Suc devices are called oil separators, and the general principle upo which they are based is to give the steam a circular motion in th separator, so that by centrifugal force the oil will be thrown agains the walls of the separator and will afterward drop down into chamber, from which it may at any time be drawn off.

CHAPTER III.

MEASUREMENT OF POWER.

To measure the amount of power used in any case there are many methods available, the great majority of which require apparatus not in the hands of the ordinary engineer. They will not therefore be discussed in this book, but the reader is referred to J. J. Flathers' "Dynamometics and the Measurement of Power," should he wish to study the subject in detail. Nearly all measurements desired can, however, be made with a fair degree of accuracy by the methods to be described, using only easily obtained apparatus. These methods are the Indicator method, Electric method, and method of the Prony brake.

The indicator and its use will be found described fully in the chapter on steam-engine appliances. If we want to know what power is being used to drive a certain tool, indicate the engine with the tool thrown off and then with it thrown on. The difference between the two powers will be the power used to drive the tool. If the power for the tool is but small compared to the power without it, this method is not very accurate, it being similar to an attempt to measure the weight of a forkfull of hay by driving a loaded cart on a hay-scales, getting its weight, and then throwing off one forkfull and reweighing, and finally subtracting the second weight from the first. If the power to be measured is a large part of the total power furnished by the engine, the method is fairly accurate, say within 10 per cent., if carefully carried out.

The electrical method is, where feasible, the quickest and most accurate, as with good instruments the readings will be correct to within 2 *per cent. If the* machine whose power of consumption *is to be measured is* already operated by an electri motor direct, all that is necessary is to connect a voltmeter of proper range to the motor terminals, and an ammeter in series with the motor, and read the two instruments. The product of the two readings divided by 746 will give the horse power used by the motor and tool. Throw the tool off and take another reading and subtract the last measurement of power from the first. The result is the power used by the tool.

If the motor is driving several tools, measure the power first with all running and then throw off the machine to be measured and get the power now required. The difference will be the power of the tool. Of course, as with the indicator method, if the machine is small compared with the others run with it by the motor, the measurement will not be so accurate.

If the machine is not already driven by a motor, it is not difficult to arrange it temporarily to be operated by one, when the measurements can be taken as above.

Example.—With a direct current motor driving a line of shafting and a printing press the following readings are taken at intervals of 10 seconds. Ammeter: 22.5, 22.0, and 21.5 ampères. Voltmeter: 224, 222, and 220 volts. The average number of volts is 222, and the average number of ampères is 22. The power is 222 × 22, or 4884 watts. With the printing press not running the average number of volts is 223 and of ampères 10, and the power is 2230 watts. The power required to drive the press is, therefore, 4884 less 2230, or 2654 watts, and the horse-power is 2654 ÷ 746, or about 3½ H. P.

If an alternating current is used, it is necessary to have a wattmeter, instead of the ammeter and voltmeter, as with such currents the product of ampères and volts divided by 746 does not give the horse-power.

The Prony brake is used to measure the power developed by an engine, water-wheel, electric motor, gas engine, etc., in any case where the power need not be transmitted to any tools or machines, but can be absorbed in the measurement. It consists as shown in the sketch, of two blocks of soft wood fitting a pull the motor to be measured, and is so arranged that by tightening p on bolts they may be made to grip the pulley more tightly. One of the blocks has an extension arm, from which is hung a pan carry weights, or else a spring balance, which is preferable. As he screws are tightened up the blocks with arm and weights end to be carried around with the pulley, but weights are added prevent this and the arm is kept balanced in a horizontal osition.

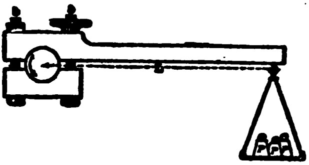
Measure the diameter of pulley, which we will suppose to be 2 et; the distance from centre of shaft to point of suspension of he weights, which we will call 4 feet. Notice what weight, say 0 pounds, is in the pan and also the number of revolutions per inute of the pulley, which we will assume to be 200.

The principle of the method is simple if we remember the principle of moments discussed in Chapter I., and also that the

$$\text{horse-power} = \frac{\text{work in foot pounds per minute}}{33000}, \text{ or equals}$$

$$\frac{\text{force in pounds} \times \text{feet per minute through which it is exerted}}{33000}.$$

The arm is balanced between the action of two forces, one due to the friction of the motor-pulley on the block, which tends to roate the arm in a direction oppoite to the movement of the hands f a watch; the other due to the eight of the arm and weight in he pan. We will for simplicity onsider that the weight of the m is so small that it can be neglected. Taking moments about he centre of the shaft we have force of friction × radius of puley = weight × distance L, therefore the force $= \frac{\text{weight} \times \text{L}}{\text{radius}}$, nd this force is exerted by the motor, and is the total force xerted *by the motor, as no other* work is being done by it. The *umber of feet per minute through* which this force is exerted



Prony Brake.

equal to the circumference of the pulley in feet (3.14 × 2) plied by the number of revolutions per minute (200).

The horse-power of the motor is, then, from the test

$$\frac{20 \times 4 \times 2 \times 3.14 \times 200}{1 \times 33000} = \frac{100.48}{33} = 3.04 \text{ horse-powe}$$

We thus have the rule:

Multiply 6.28 by the weight, by the length of lever from of shaft to point of support of weight, by the number of revo per minute, and divide the product by 33,000.

If the length of arm be made 5 feet 3 inches, the rule plified, so as to read, multiply the weight by the number o lutions per minute and divide by 1000.

In using the brake the surface of the blocks should greased. In special cases, where this brake is much us pulley is made hollow and a stream of cooling water is m run through it for the purpose of carrying off the heat developed. As mentioned above, a spring balance may ployed instead of weights. Another device is to have t put on so that its outer end tends to go down instead of make it press by means of a stiff stick on the platform of a whose arm is kept balanced by the sliding weight. In ei these cases the average weight is employed in the calculati

For measuring the power required by vehicles, such as s railway cars, a spring dynamometer is used, with an arran for recording automatically the pull on the spring at each and the velocity of the car as well. From these two r the power is calculated in a manner similar to the above. absence of such a dynamometer the measurement can be m the use of a spring-balance and a watch. The balance is i between the locomotive and the vehicle to be pulled, and r taken at regular intervals of time. By making time obser as the car passes points at known distances apart, the a velocity of the car can be calculated, and this with the a *pull on the spring*-balance serves to calculate the horse-po

QUESTIONS.

Of what elements are all machines made up?

What do machines do?

What is mechanics?

What is force?

What different kinds of force exist?

What is the unit of force?

Define inertia.

Give the laws of motion.

What is "perpetual motion," and why is it impossible?

What are the different kinds of motion?

Define velocity.

What is the difference between velocity and acceleration?

What is the relation between the velocity of a freely falling body and the height from which it has fallen?

Define mass.

What is the relation between the weight of a body and its mass?

Is its weight at different parts of the earth the same?

Is its mass always the same?

What is its relation to force and acceleration?

What is momentum?

What is energy?

How is energy related to force?

How many kinds of energy are there?

What are some of the principal forms of energy?

Whence comes all of the energy on the earth?

State, in a general way, the transformations of energy which occur in the production of mechanical power by means of the steam-engine.

Can we create or produce energy?

Can we produce force?

What is power?

What *is the difference between* power and energy?

Define a horse-power?

What is a moment, or statical moment?

When two forces are acting in opposite directions upon a pi oted body how can we tell in what way the body will move?

What are the three classes of levers?

How does the wheel and axle differ from a lever?

With a single pulley do we gain any force?

With a set of pulleys how is it that a large weight can raised by a small force?

Give the rule for the gain in force by using a wedge.

What other mechanical element does the screw resemble?

What are the principal methods of transmitting power?

Why is shafting now made of steel instead of iron.

In proportioning shafting what two requirements must be s isfied?

What are the advantages of belting over toothed gears for t transmission of power?

What are the advantages and disadvantages of rubber be over leather?

What is a common rule for determining the width of belt transmit a certain horse-power?

Why will a certain size belt 30 feet long transmit more hoi power than the same belt 20 feet long?

Why do the rules of different authorities for the calculation width of belts differ so much from one another?

What advantage has rope driving over belt transmission?

What are the two general methods of using ropes?

What is the pitch of a gear wheel?

Define the thickness of a tooth.

Define backlash.

What are spur gears, and for what used?

How is pitch measured with bevel gears?

For what are friction clutches used?

On what general principle do they operate?

What are the advantages of pneumatic transmission of po over other methods?

Why are air compressors usually made duplex, or rather compound?

What is the advantage of the intercooler?

Why is the capacity of compressors less at high altitudes?

For what are receivers used?

How does the efficiency of air motors compare with that of electric motors?

Generally speaking, where are alternating current systems used for transmitting power?

What type of direct current motor is generally required for driving tools?

What is the advantage of using a 500-volt system rather than a 220-volt system?

What disadvantages occur to you?

What requirement determines the size of wire connecting generator and motor?

When several motors are supplied by one generator, is the generator size necessarily equal to the sum of the motor capacities?

For what purpose is a lubricant used?

What are the requirements for a good oil?

Describe an oil filter.

What is an oil separator, and on what principle does it operate?

Describe a system for automatic oiling.

What are the common methods of measuring power?

Which is the most accurate?

What instruments are needed in the electrical method, using direct currents?

Are these suitable when alternating currents are used?

Describe the Prony brake and its use.

What is the usual length of the lever arm, and why?

What is a dynamometer?

For what purpose is a spring dynamometer used?

How is *the motion of a body* down an inclined plane calculated?

What is the unit of work?

What are the six mechanical elements?

Give the rule for finding the diameter of a shaft to transmit certain number of horse-power at a certain speed.

What is the objection to having belts run vertically?

What is the rule for determining the length of an open belt?

What is the rule for a crossed belt?

How would you measure the length of a belt coiled up?

When idlers are used in rope-driving what precautions shoul be taken in arranging them?

At what speeds do the ropes ordinarily travel?

How would you find the diameter of a driven-pulley to run at certain speed, if you have given the diameter and number revolutions of the driver?

What is the rule for finding the number of revolutions driven pinion when the number of revolutions of the driver given and the number of teeth in each wheel?

How is the pressure in a pneumatic transmission regulated?

Give some figures showing the number of cubic feet of air by air-motors for each horse-power-hour.

PART II.

HEAT, FUEL, GASES, WATER, AND STEAM.

CHAPTER IV.

HEAT.

According to the dynamical or mechanical theory, heat is the ult of motion among the atoms of matter, or, as it may be erwise stated, of inter-atomic movement; and this motion is able of being propagated through space, from one body to other, by undulations of a so-called ether assumed to be every-ere existent in the universe.

The relative effect of such heat producing motion, or, in other ords, the relative proportions of heat required to cause given ects, may be accurately indicated by numbers, just as if heat ere a ponderable agent; and it is usual to speak of heat as if it ere an independent material substance: thus, it is said to be olved, or emitted, radiated, conducted, absorbed, and stored up, accumulated. As a variable amount of the heat evolved in e combustion of a body is absorbed in the work of effecting terations in the physical condition of the combustible elements cessary to their effective oxidation, it is impossible to estimate e absolute quantity of heat evolved by the combustion of a dy; yet the relative quantities of heat evolved by the com-stion of different bodies which may be utilized, can be accurately termined.

One of the remarkable effects of the application of heat to tter is, that the *same amount will* affect equal weights of dis-*ilar kinds in different degrees.* Thus, the amount of heat that will raise 1 lb. of water from 100° to 200° Fah, will raise 30 of mercury through the same range. The amount that will r 1 lb. of water 1°, will raise 14 lbs. of air.

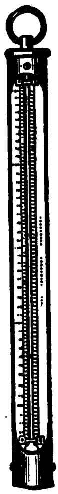
The capacity of a body for heat is termed its *specific heat,* may be defined as the number of units of heat necessary to r the temperature of 1 lb. of that body 1° Fah.

The thermal unit, or unit of heat, as it is termed, is the qu tity of heat that will raise 1 lb. of pure water 1° Fah., or fr 39° to 40° Fah.

Temperature is a measure, not of the amount of heat in a bo but of its tendency to give up its heat to other bodies. Ther the same difference between temperature and heat as ex between pressure and work or energy. Heat corresponds and is a form of energy. Temperature corresponds to press or force. Two bodies may be at the same temperature a yet possess very different quantities of heat. For example cubic inch of iron and a cubic foot of iron may both be put the same oven, and after remaining there for a considerable ti they could both be at the same temperature. The hand pla on each would feel that both were equally hot, and a therm eter laid on each would give the same reading, and finally, they were placed so as to touch neither would give any heat the other. But the cubic foot has 1728 times as many units heat as has the cubic inch, as could be proved by putting t cubic foot in a tub of water containing 1728 pounds, and t cubic inch into a tub containing one pound. The rise in te perature would be the same in the two tubs. That is, the cub foot raises the temperature a certain number of degrees, of 17 times as much water as does the cubic inch; it has therefore 17 times as many heat units.

The thermometer is the instrument used for measuring te peratures, and it depends upon the principle that liquids expa under the action of heat. While for a standard use is made *the air thermometer,* yet for common use the mercury thermom *is employed.* It consists of a bulb and glass stem of unif

A sufficient quantity of mercury having been introduced, ›iled to expel the air and moisture, and the tube is then ically sealed. The properties of mercury which render it ble to all other liquids are these: it supports, before it ıore heat than any other fluid, and endures a greater cold ould congeal most other liquids.



The Uptake Thermometer.

The standard points are ascertained by immersing the thermometer in melted ice and in the steam of water boiling under the pressure of 14·7lbs. on the square inch, and marking the positions of the top of the column. The interval between those points is divided into the proper number of degrees,—100 for the Centigrade scale, 180 for Fahrenheit's, and 80 for Reaumur's.

otwell
›meter.

The word "zero" is of Arabic origin, and means empty; hence nothing. Absolute zero is a temperature which is fixed by reasoning, although no opportunity ever occurs for observing it. It is the temperature corresponding to the disappearance of gaseous elasticity; or, in other words, the point where gas would become a solid, as where water becomes ice. This temperature is called zero in reference to all the gases, and the positions of the absolute zero on the ry scales would be

eaumur's scale	. 219·2	below 0°
ɜntigrade	. 273.1	"
ahrenheit	. 461·22	"

›s *for Comparing Degrees of Temperature Indicated by Dif-Thermometers.* 1. *Multiply* degrees of Centigrade by 9 and by 5; or *multiply degrees of* Reaumur by 9 and divide by 4. *2 to the quotient in either* case, and the sum is degrees Fahrenheit. 2. From degrees of Fahrenheit *subtract* 32; *multiply* t remainder by 5, and *divide* by 9 for degrees Centigrade; or *m* *tiply* by 4, and *divide* by 9 for degrees Reaumur. The abbrevi tion for Fahrenheit is "Fah." or "F."; for degree, °.

TABLE FOR CHANGING FROM CENTIGRADE TO FAHRENHEIT DEGREES.

°F	°C	°F	°C	°F	°C	°F	°C
-40	-40	194	90	428	220	662	350
-31	-35	203	95	437	225	671	355
-22	-30	212	100	446	230	680	360
-13	-25	221	105	455	235	689	365
- 4	-20	230	110	464	240	698	370
5	-15	239	115	473	245	707	375
14	-10	248	120	482	250	716	380
23	- 5	257	125	491	255	725	385
32	0	266	130	500	260	734	390
41	5	275	135	509	265	743	395
50	10	284	140	518	270	752	400
59	15	293	145	527	275	761	405
68	20	302	150	536	280	770	410
77	25	311	155	545	285	779	415
86	30	320	160	554	290	788	420
95	35	329	165	563	295	797	425
104	40	338	170	572	300	806	430
113	45	347	175	581	305	815	435
122	50	356	180	590	310	824	440
131	55	365	185	599	315	833	445
140	60	374	190	608	320	842	450
149	65	383	195	617	325	851	455
158	70	392	200	626	330	860	460
167	75	401	205	635	335	869	465
176	80	410	210	644	340	878	470
185	85	419	215	653	345	887	475

For temperatures intermediate between the values **in the ab** table proceed as follows: Suppose we want to know **what te** perature Fahrenheit corresponds to 92° C.

From the table above, 90° C. corresponds to 194° **F.**
" " below, 2° C. " 3.6° **F.**
Adding, we have......92° C. " 197.6° F.

suppose we want to know what temperature centigrade sponds to $-32°$ F. or 32° below zero.

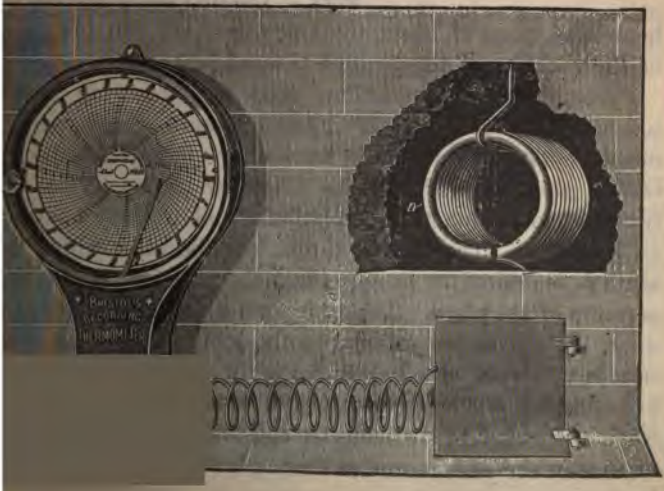
om the table above, $-31°$ F. corresponds to $-35°$ C.
" " below, 1° F. " .555° C.
btracting, we have $-32°$ F. " $-34.445°$ C.

uivalent Values of Fahrenheit and Centigrade Degrees.—

1° C. = 1.8° F.
2° C. = 3.6° F.
3° C. = 5.4° F.
4° C. = 7.2° F.
5° C. = 9.0° F.

1° F. = 0.555° C.
2° F. = 1.111° C.
3° F. = 1.667° C.
4° F. = 2.222° C.
5° F. = 2.778° C.
6° F. = 3.333° C.
7° F. = 3.889° C.
8° F. = 4.444° C.
9° F. = 5.000° C.

cording Thermometers.—The ordinary mercury thermom s not capable of recording the rise and fall of the mercury



column, so that in recording instruments the expansion o
of shape of a metal tube is employed instead of mercur
motion due to expansion is multiplied so as to give the
considerable movement for a very slight change in the
the tube. The cut illustrates one form of this instrumen

is made like a steam-gaug
coiled hollow spring carry
pointer is connected by a pip
coiled tube placed at the poi
temperature it is desired to
The tube is filled with alco
if the coil D is heated the alc
panding puts an increased pre
the hollow coil in the instru
increases the reading of the
The record is made by a spe
carrying fluid, which rests
paper dial carried on a me
which is made to turn by
work. The dial being marke
hours and parts of hours, the tracings of the pen give,
of the variation of temperature throughout the day.

Pyrometers are instruments used for measuring ve
temperatures, such as 600° F. and upward, the mercu
mometer not being available much above 600° F., as th
ization point is 675° F. The Chatelier pyrometer is
trical circuit, a junction of platinum and iridium, cont
an iron tube. The tube is thrust into the place whose
ature it is desired to measure, and the junction attains
perature of the place. This causes an electric pressure
up in the circuit proportional to the temperature, and t
sure is measured on a galvanometer in the circuit. The
ment having previously been tested in a temperature wi
range of a standard thermometer and the reading of the
and that of the galvanometer having been noted, a compa

reading of the galvanometer at any time with its standard read-
will give the temperature of the chamber in which it is placed.

olor is a rough indication of temperature. For example, in
ting up a bar of iron it commences to show color at about
0° F., it is cherry-red at about 1700° F., orange at about
0° F., and white at about 2500° F.

The effect of the application of heat to a body is to expand it
cept in the case of a few substances, like water, at certain tem-
ratures near their point of solidification], and the amount of
pansion for each degree rise in temperature is quite regular
d is called the coefficient of expansion. Gases expand $\frac{1}{492}$ of
eir volume at 32° F. for each degree F. of rise in temperature,
d it is for this reason that the idea of an absolute zero of tem-
rature has arisen. For gases of course contract $\frac{1}{492}$ of their
lume for each degree the temperature falls. There would be
en such a temperature that the volume would be zero and this
mperature is called the absolute zero, it being 492° F. below
ezing point, or − 460° F.

For solids the *linear coefficient of expansion* or increase in length
r one degree rise in temperature is usually of more value than
e change in volume or cubical expansion. The cubical expan-
n equals three times the linear expansion.

COEFFICIENTS OF LINEAR EXPANSION OF SOLIDS.

uminum	.0000123	Masonry, brick	.0000025 .0000050
ass, cast	.0000096	Plaster, white	.0000092
" plate	.0000105	Platinum	.0000048
onze	.0000099	Porcelain	.0000020
ment, Portland	.0000059	Silver	.0000108
ncrete	.0000080	Slate	.0000058
pper	.0000089	Steel, cast	.0000064
ass, flint	.0000045	" tempered	.0000069
ld	.0000079	Stone, sandstone	.0000065
on, wrought	.0000065	Tin	.0000116
" cast	.0000056	Wood, pine	.0000028
ad	.0000157	*Zinc*	.0000141
arble, *between*	*.000030* *.000080*		

COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS.

Alcohol	.00061	Nitro-benzine	.
Benzine	.00077	Olive oil	.
Carbon bisulphide	.00082	Petroleum, sp. gr. = 85	.
Ether	.00012	Salt water, 1.6 p. c. solution	.
Hydrochloric acid	.00027	Sulphuric acid	.
Mercury	.00010	Turpentine	.

MELTING POINTS OF SOLIDS.

Owing to the difficulty of accurately determining the moment of melting the values given by different observers Those in the table are an average of the best results.

Aluminum	1160°F.	Nickel	27
Antimony	815	Pitch	
Bismuth	515	Platinum	31
Brass, yellow	1850	Silver	17
Copper	2000	Spermaceti	1
Gold	1975	Steel	24
Glass	2380	Stearine	1
Iridium	3940	Stearic acid	1
Iron, pure	2975	Sulphur	2
" white pig	1970	Tallow	
" gray	2190	Tin	4
Lard	95	Zinc	7
Lead	620	Wax	1
Mercury	–37.3		

BOILING POINTS OF LIQUIDS AT ATMOSPHERIC PRESSURE

Acetic acid	248°F.	Linseed oil	6
Alcohol	173	Mercury	6
" wood	151	Naphtha	1
Ammonia, liquefied	– 37.3	Nitric acid	1
" water	140	Petroleum, refined	3
Benzine	177	Sulphur	8
Chloroform	142	Sulphuric acid	6
Carbon bisulphide	118	Turpentine	3
Coal tar	325	Water, pure	2
Ether	96	" sea	2
Glycerin	554	" saturated brine	2
Hydrochloric acid (sol.)	230		

The temperature at which boiling takes place rises if the pressure d and is less if the pressure is less, so that on high mountains, as, e, 10,000 feet above sea level, the boiling point of water is 193° F. peaking water boils at 1° less for every rise in height above sea i0 feet.

ıechanical equivalent of heat is the amount of work per- ›y the conversion of one unit of heat into work, and the *al theory* of heat is based on the assumption that heat ɛ are mutually convertible.

ethod by which the mechanical equivalent is determined simple. A centrifugal churn is turned by an electric ıe churn being jacketed with non-conductors of heat, so least possible heat is carried off by the outside air. A umber of pounds of water, say 50, are put in the churn temperature, which we will suppose to be 60° F., is care- asured. At a certain time the motor is started and run, ninutes, the ampères 1.628 and volts 100 being carefully ıd also the temperature at the end of the 60-minutes' run, ɜ will suppose to be 70° F.

ower delivered to the motor is 1.628 × 100 Watts, or $\frac{100}{\ } = \text{H. P.}$ As the work in $\frac{\text{foot pounds per min.}}{33000} = \text{H.P.},$ the number of foot pounds of energy given to the motor 432222, and if the efficiency of the motor is 90 per cent. ʒy in foot pounds given to the water in the churn, and all ıeating it, is 90 per cent. of 432222 or 389000. This heat) pounds of water, 10° F., and therefore 500 heat units ›duced, which were the exact equivalent of the 389000 ıds supplied the churn. Therefore the mechanical equiva- ne heat unit is 389000 ÷ 500, or 778 foot-pounds of work. e, in the many experiments which have been carried on to e the value of the mechanical equivalent great refinements ethods have been introduced which do not have any place ɔlume.

nsference of heat from one body to another takes plac in three different ways—by radiation, convection, and by c duction.

Radiation is transmitted in the same manner as light by setti up wave motions in the "aether" which pervades all space. Th radiation is propagated in straight lines just as with light, an like it, can be reflected and refracted. In fact, radiant heat di fers only from light in that the number of wave fronts passing given point in one second is much less than in the case of lig The time in which a heated body will give up its heat depends the nature of the body and the state of its surface, rough a blackened surfaces radiating heat much more quickly than lig and smooth ones. The following table gives the radiating pow of several substances with water taken as the standard.

RELATIVE RADIATING POWERS OF DIFFERENT SUBSTANCES

Water	100	Blackened tin	
Lampblack	100	Clean tin	
Writing paper	100	Scraped tin	
Glass	90	Ice	
India ink	88	Mercury	
Bright lead	19	Polished iron	
Silver	12	Copper	

The better reflector a body is the worse radiator it is, there steam pipes should be polished and kept bright, or, if cove should be painted white.

Convection of heat is the transfer and diffusion by means the actual motion of particles of a body, and can only take p in liquids and gases. If a hot piece of iron, for example, is pended in air, part of its heat is transferred by radiation, the rest by convection. The particles of air next to the iron heated by direct contact or conduction and tend to rise, allow cooler particles to take their place. These in turn are heated replaced by others. In this way currents of air are set up, ca convection currents, which gradually carry away the heat of iron and diffuse it equally throughout the room.

Conduction of heat takes place when a body is placed in act contact with a hotter body. The heat is transferred to the co diffused over it until all parts of it attain the same tem- The time required for this to take place depends on the the body and is a measure of its conducting power for heat.

Relative Conducting Power of Metals.

	100	Iron, cast	16
	75	Tin	15
	55	Steel, soft	11
	36	Lead	8
	31	Platinum	8
	21	Antimony	4
ron	20	Bismuth	1.8

ive Conducting Power of Different Materials.

ate	100
e	71·95
k	61·70
lk	56
m	45
d	33·66
od	27·61
d Plaster	25·55
of Lime	20·26
of Lime and Sand	18·70
shes, Shavings, Hay, and Straw	25–85
and Tan-Bark (fine)	17–20
Wood or Asbestos, cemented	18–20
estos, in thread	13–15
dered Charcoal	14–16
Mineral Wool, Hair-Felt, Cat-Tail, etc.	10–13
ineral Wool, Raw Silk, Cotton, etc., quite loose	8–10

cting Power of Various Substances.—The matter of a good non-conductor of heat is of the greatest im- in connection with pipe coverings. Extensive experi- ade by Prof. Ordway *for the* Boston Manufacturers' *ire Insurance Company are* summarized in the follow- *where the first column of* figures gives a comparison

of the relative value of materials. The first nine, while
lent non-conductors, are unsuitable, as they are liable to be
carbonized and ignited from contact with hot pipes.

Substance 1 inch thick. Heat applied, 310° F.	Pounds of Water heated 10° F., per hour, through 1 square foot.	Solid Matter in 1 square foot 1 inch thick, parts in 1000.	
1. Loose wool	8.1	56	
2. Live-geese feathers	9.6	50	
3. Carded cotton wool	10.4	20	
4. Hair felt	10.3	185	
5. Loose lampblack	9.8	56	
6. Compressed lampblack	10.6	244	
7. Cork charcoal	11.9	53	
8. White-pine charcoal	13.9	119	
9. Anthracite-coal powder	35.7	506	
10. Loose calcined magnesia	12.4	28	
11. Compressed calcined magnesia	42.6	285	
12. Light carbonate of magnesia	13.7	60	
13. Compressed carbonate of magnesia	15.4	150	
14. Loose fossil-meal	14.5	60	
15. Crowded fossil-meal	15.7	112	
16. Ground chalk (Paris white)	20.6	258	
17. Dry plaster of Paris	30.9	368	
18. Fine asbestos	49.0	81	
19. Air alone	48.0	0	1
20. Sand	62.1	527	
21. Best slag wool	13.		
22. Paste of fossil meal with hair	16.7		
23. " " " asbestos	22.		

Cooling of Liquids and Solids.—The quickness with whi
solid body cools in a liquid is approximately the same, wh
it be placed near the surface or near the bottom. It is slig
less when the body is brought immediately under the sur
The nature of the external surface of the cooling body has
little influence. The velocity of cooling increases very cons
ably for the same body immersed in the same liquid with inc
ing temperature of the latter. If the cooling power of wat
taken at 1, that of alcohol is equal to 0.56; mercury, 2.07;
phate of copper, 1.03, and common salt, 1.05.

Latent Heat.—When heat is applied to a liquid its tem
ture, as indicated by a thermometer suspended in it, rises stea
and the product of its rise in temperature multiplied by its
cific heat will equal the number of heat units applied to i

ıches a point where vapor is given off, and, although heat eing added to it, the temperature no longer rises, but :onstant till all of the liquid has been changed into vapor. ; which goes to change the state of the substance from liquid to that of a gas, and which does not show itself on mometer, is called latent heat. After all the liquid to vapor any further addition of heat raises the temperahe vapor.

ıtent heat of vaporization of any substance is the number ınits needed to change one pound of the substance from a a gaseous condition at a given atmospheric pressure.

HEAT OF VAPORIZATION.			
	965.	Acetic acid	152.8
	376.	Carbon disulphide	150.8
ood	475.	Turpentine	133.
	167.	Mercury	111.6

Note: the right-hand column begins with "Ether 164." on the header line.

t Heat of Fusion.—When a solid is heated a similar ccurs, the temperature rising till the melting-point is and after that remaining constant till all is melted, ich it rises again if heat is still added. The heat neceschange one pound from the solid to the liquid state at eric pressure is called the latent heat of fusion. The table : values of the latent heats for several substances at a pressne atmosphere:

ENT HEAT OF FUSION.		Cast iron	41.4
	175.	Silver	37.9
ti	148.	Tin	25.7
	142.6	Bismuth	22.7
	97.2	Sulphur	16.8
	50.6	Lead	9.7
	48.9	Mercury	5.1

ıeat of the liquid at any temperature is the number of its required to raise one pound of the substance from :ing-point to that temperature.

otal heat *at any temperature* is the sum of the heat of the *that temperature plus the* latent heat of vaporization.

CHAPTER V.

COMBUSTION AND FUELS.

Combustion is a subject of interest to the engineer, manuf turer, and individual, and must ever continue to be so, while t steam-engine is used as a motive power, and so long as artific heat is employed for manufacturing and domestic purposes, well as for the preservation of animal life. This subject has heretofore received that consideration which its importance in economical point of view so eminently deserves. This arose, part, from the lavish hand with which a bountiful Nature has plied us with minerals, woods, and cereals, and the close pr imity of the source of supply to the avenue of demand; but t increase of population and demand, and the diminution in supp are making the examination of the subject an imperative nec sity. It is quite common to see in the neighborhood of ma facturing establishments, and even households, splendid lumps the finest qualities of anthracite coal, nearly pure carbon, lying the highway, to be forced into the ground by the pressure of h or wheel, and after rain storms dumping-grounds glisten w kernels of coal that have never been exposed to the fire, wh are as fine as, and in many respects superior to, that which has b placed in the furnace. The same thing may be said of oil, cott waste, piston-rod packing, etc.; but, as the cost of material has be paid out of the profits of production, such carelessness is g erally followed by retributive justice; and the old adage wh says "that a wilful waste is generally followed by a woeful wa is sooner or later realized.

Combustion is the result of chemical alterations of a vio *character, and the* heat thus evolved is merely an incidental non of a vehement combination of various materials. In oustion, the carbon and oxygen have so great a chemical af- y for each other, that they rush violently together, and by the e of their combustion produce instant heat. Other substances e an affinity for oxygen and burn freely in it, such as hydro- , sulphur, chlorine, and the various hydrocarbons, as marsh , illuminating gas, acetylene, etc. Combustion is rapid oxida- ı accompanied by flame or fire.

ire. — Fire is one of the oldest chemical phenomena. Its dis- ery was one of the greatest boons conferred on mankind, as h it arose sociability, the family joys of the domestic hearth, industries and arts, together with the wonders they have pro- ced, and still produce from day to day. Hence, we can readily derstand how it is that fire has ever been, and still is, among tions the object of a special worship (priests of Baal, Gebers, indoos, Brahmans, etc.), and has often figured in the religious funereal rites of nations most remote from each other, both time and space, as the Chaldees, Hebrews, Greeks, Romans, ruvians, Mexicans, etc. But how and when this great discovery s made, in the absence of which we can hardly conceive of the ssibility of human arts, or even of human existence, is un- own.

Flame. — Flame is gas or vapor, of which the surface, in con ct with the atmospheric air, or other supporter of combustion, rns with the emission of light. The luminosity of flame is nerally admitted to be caused by the presence of particles of lid matter within, or in immediate contact with, the gas in active mbustion.

Smoke. — Smoke is the product of imperfect combustion, caused her by a want of oxygen or a want of temperature. Bitu- inous, coal contains from 5 to 6 per cent. of hydrogen, which ites with the oxygen necessary to combustion, and constitutes ter. A ton of bituminous coal will make nearly one-third of ton of water *in the form of steam*. That this steam is black, s *not necessarily indicate* the presence of much carbon, as a

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grain of soot, if distributed evenly in fine particles throug cubic foot of steam, would color it blacker than the ace of spa Too much air produces smoke, even though it brings oxyge the fuel, for it tends to lower the temperature of the carbon b its igniting-point and thus prevents its complete combustion.

To ensure complete combustion it is necessary to have a ficient supply of air, to thoroughly mix the combustible air, and to have the combustible and the air maintained sufficiently high temperature. The higher the temperatur which the materials are fed to the fire the more perfect wil the combustion.

The following table shows the number of heat units prod by the complete combustion in air of one pound of the [illegible]

HEAT OF COMBUSTION.

Acetylene	20420	Gas, coal. [illegible]	[illegible]
Alcohol	12930	" [illegible]	[illegible]
" wood	9560	Gu[illegible]	[illegible]
Benzine	17960	I[illegible]	[illegible]
Carbon to carbonic acid	13950	[illegible]	[illegible]
" disulphide	5840	[illegible]	[illegible]
Carbonic oxide	42[illegible]	[illegible]	[illegible]
Dynamite (75 per cent.)	2[illegible]	[illegible]	[illegible]

Spontaneous combusti[illegible] attracted at different ti[illegible] ophers, and many th[illegible] development. G[illegible] cotton-waste so[illegible] to a temperat[illegible] actual com[illegible] extensive [illegible] jute, an[illegible]

The [illegible] *prese*[illegible] *incr*[illegible] *ric*[illegible]

ites were not the most subject to spontaneous combustion.
ording to him, air is rapidly absorbed by the coal, and the
gen of the air then combines with the organic components to
duce carbonic acid and develop heat. According to all prob-
lities, however, the heat which determined the spontaneous
ıbustion is due both to the oxidation of the iron and to that
he carbonized matters. This confined in badly-ventilated holds
edily reaches a temperature sufficiently high to produce com-
tion.

hat most of the bituminous coals (English and American) are
ject to spontaneous combustion when in bulk, and under favor-
e circumstances, has long been known. Experiments by Green-
ann have also proved conclusively that an exposure of bitu-
ıous coal in heaps to the action of the weather for a period
ying from two weeks to a year results in a large percentage of
ı. This loss is in the nature of a slow or incomplete combus-
ı; it is greater and more rapid in large heaps than in small,
l is also favored by the greater or less state of subdivision of
coal, large fragments losing proportionably less than smaller
s. The loss varies from 5 to 25 per cent.

he higher the temperature the more rapid is the combustion.
heat around the coal-bunkers of steamships must necessarily
very great, from their close proximity to the boilers and fur-
es; and in sailing-ships containing large quantities of these
ls in bulk, taken on board mostly wet, the generation of heat
he point of ignition seems to be only a question of time. The
hur and volatile matter in bituminous and hydrogenous coals
the active agents in spontaneous combustion, and the finer the
ticles the more favorable is the condition for producing that
ılt. The large number of disasters, which have occurred from
spontaneous combustion of bituminous coals on board of steam-
ps and sailing-vessels, has called public attention to the matter.
though the manner by which bituminous coal stored in vessels
omes *ignited is not yet determined*, it has been demonstrated
the conditions for the work of spontaneous combustion exist

wherever large bodies of bituminous coal are stored in close co partments.

From the foregoing considerations, it would seem that, wh spontaneous combustion takes place among coals or other su stances, drowning out with water is not always effective; as, thou it extinguishes the fire, it leaves in the coal a condition of thi very favorable to a renewed ignition at any moment. A terri explosion of coal-gas recently occurred on board of a steamship Liverpool, by which fourteen men were injured, some of th seriously, in consequence of a quantity of wet coal having be placed in the bunkers and the hatches closed.

Fuel.

The word fuel is used to denote substances which may be bur by means of atmospheric air with sufficient rapidity to evolve h capable of being applied to economical purposes. Fuel con either of vegetable matter or of the products of the natural artificial decomposition of such matter. Vegetable matter, whi consists principally of woody tissue, is composed of carbon, h drogen and oxygen, comprising the organic part, and a small p portion of so-called earthy matter, that which is inorganic. T sun is the source of the heat-producing power of fuel, since t organic parts are derived from water, and, except in particu cases, from the carbonic acid of the atmosphere, which are deco posed in the economy of plants by the action of solar light.

The principal fuels used in the production of steam are co coke, wood, petroleum, natural gas, peat, and refuse of vario kinds, either animal or vegetable. These fuels are all made u of carbon and hydrogen, while most of them contain in additi oxygen, nitrogen, and sulphur, with traces of mineral substanc The carbon is the principal heat-producer and the hydrogen co second, none of the other elements being of any value in the p *duction of heat.* In the process of combustion the carbon bur *to carbonic acid,* the hydrogen to water, the sulphur to sulphur ıe minerals to ashes, the nitrogen remains unchanged and 'gen unites with the hydrogen to form steam.

ogen in fuel must always be in association with carbon, but practically free from hydrogen may be procured abun- ınd applied as fuel. In all fuel containing carbon, hydrogen, 'gen, the proportion of hydrogen may be equal to or greater, er less, than that required to form water with the oxygen. ly the hydrogen in excess of this which is available as a of heat, so that, in the combustion of a substance whose tion is represented by carbon and water, the carbon alone ıurce of heat. The hydrogen existing in combination with in the state of water, so far from contributing to the actual of heat produced, must be evaporated at the expense of developed by the combustion of the carbon.

compare different fuels, and assign them a value for heat- poses based on their chemical constitution, we will find roleum is about 25 per cent. superior to all others theoret- in round numbers, it is capable of evaporating 15 lbs. of er pound of fuel, while a pound of anthracite coal can te 11 lbs., and a pound of coke only about 9 lbs.; these varying, to a certain extent, with the different qualities of ɜ.

hemical properties of coal are, free carbon, hydro-carbons, oxygen, and hydrogen, with solid matter termed ash; the ons of these vary considerably. In some instances, the ıtter is 25 per cent., while with superior coal, only 6 or 10 . The products of combustion are carbonic acid gas, ni- ıir, ashes, and steam.

oxygen necessary for the combustion of coal is derived ɜ atmosphere. One pound of carbon in combustion unites 6 lbs. of oxygen, and the product is 3·66 lbs. of carbonic s. From this it will be seen that to obtain 2·66 lbs. 'en 11 lbs. of air would have to be brought into contact ɜ pound of coal *(if pure carbon)* to render its combustion complete; but, as coal contains hydrogen, it is found that inste of 11, 12 lbs. are required.

Carbon.—Vegetables, when burnt or distilled in close ves till their volatile parts are entirely separated, leave a black, brit and cinereous substance which constitutes the greater part of woody fibre, and is called *charcoal.* Charcoal contains a porti of earthy and saline impurities, but, when entirely freed from th and other impurities, a solid, simple, combustible substance mains, which is called carbon. Carbon exists naturally in a of greater purity than can be prepared by art. The diamond pure carbon crystallized, and when pure is colorless and tran rent. It is the hardest substance known; and, as it sustain considerable degree of heat unchanged, it was formerly consider to be incombustible. It may, however, be consumed by a burni glass, and even by the heat of a furnace. The difficulty of burni it appears to arise from its hardness; for Morveau and Tenn have rendered common charcoal so hard, by exposing it for som time to a violent fire in close vessels, that it endured a red he without catching fire. Common charcoal contains only 64 part of diamond, or pure carbon, and 36 of oxygen in every 100.

The common charcoal of commerce is usually prepared fro young wood, which is piled up near the place where it is cut conical heaps, covered with earth, and burnt with the least p sible access of air. When the fire is supposed to have penetrat to the centre of the thickest pieces, it is extinguished by entir closing the vents. When charcoal is wanted very pure, the pr duct of this mode of preparing it will not suffice; for the man facturing of the best gunpowder, it is distilled in iron cylinde Chemists prepare it in small quantities in a crucible covered wit sand, and after they have thus prepared it, they pound it, an wash away the salts it contains by muriatic acid; the acid is re moved by the plentiful use of water, and afterwards the charco is exposed to a low red heat. Pure charcoal is perfectly tastele and insoluble in water.

Charcoal *newly* prepared absorbs moisture with avidity.

rbs oxygen and other gases, which are condensed in its
quantity many times exceeding its own bulk, and which
out unaltered. Fresh charcoal allowed to cool without
to air, and the gas then admitted, will absorb 2.25 times
of atmospheric air immediately, and 75 per cent. more
r five hours; of oxygen gas about 1.8 immediately, and
more; of nitrogen gas, 1.65 immediately.
llowing table (from D. K. Clark) gives the relative val-
veral combustibles, with perfect combustion. In practice
than 60 to 70 per cent. of the evaporative effects will be
The coal is English coal, and gives a higher value than
n coals.

EAT EVOLVED BY VARIOUS FUELS AND THEIR EQUIV- T EVAPORATIVE POWER, WITH THE WEIGHT OF OXYGEN VOLUME OF AIR CHEMICALLY CONSUMED.

UEL.	Weight of Oxygen Consumed per lb. of Fuel.	Quantity of Air Consumed per lb. of Fuel.		Total Heat of Combustion of 1 lb. of Fuel.	Equivalent Evaporative Power of 1 lb. of Fuel from and at 212°.
	Lbs.	Lbs.	Cu. ft. at 62°.	B. T. U.	Lbs.
	8.0	34.8	457	62000	62.40
{ Making Carbonic Acid.	2.66	11.6	152	14500	15.0
	1.00	4.35	57	4000	4.17
ge dessicated	2.45	10.7	140	14700	15.22
"	2.49	10.81	142	13548	14.02
rfect	2.04	8.85	116	13108	13.57
	2.74	11.85	156	17040	17.64
sicated	1.40	6.09	80	10974	11.36
cent. moisture	1.05	4.57	60	7951	8.20
per ct. moist.	0.98	4.26	56	8144	8.43
	3.29	14.33	188	20411	21.13
ils	4.12	17.93	235	27531	28.50

e Value of Coal.—The tables on pp. 106, 107, taken from
" give the constituents and number of pounds of water
ed per pound of coal. These values are the theoretically
alues, and in practice not over 70 per cent. is liable to
ed.

TABLE OF AMERICAN COALS.

COAL Name or Locality.	Constituents in Per Cent of Total Weight.					Fuel Value Per Lb. of Coal.		
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	B. T. U. Calculated.	B. T. U. by Calorimeter.	Theoretical Evaporation in lbs., from and at 212°.
ARKANSAS.								
Coal Hill, Johnson Co.	1.35	14.93	74.06	9.66	3.04	13713		14.1
Coal Hill, Johnson Co.	1.70	14.60	74.91	8.79	3.04		11812	12.22
Huntington Co.	1.30	18.95	71.51	8.24	0.78		11756	12.17
Huntington Co.	1.30	18.90	73.15	6.65	0.75		11907	12.32
Huntington Co.	1.27	18.89	71.74	8.10	0.65		12537	12.97
Lignite						9215		9.54
Jenny Lind, Sebastian Co.	1.26	17.64	72.48	8.62	2.11	13964		14.4
Spadra, Johnson Co.	1.47	13.27	78.63	6.63	1.60	14420		14.9
COLORADO.								
Lignite						13560		14.04
Lignite						13865		14.35
Lignite, Slack	14.80	32.00	42.86	10.34	0.76	8500		8.80
Lignite, Slack, North Colorado	18.88	31.74	40.08	9.30	0.61			
Rouse Mine	3.13	37.32	30.00	8.25				
ILLINOIS.								
Big Muddy, Jackson Co.	7.39	28.28	53.87	10.46	0.98		11466	11.87
Big Muddy, Jackson Co.	6.12	30.95	58.74	9.19	1.22		11529	11.93
Big Muddy, Jackson Co.	5.85	31.84	55.72	6.59	2.92		11781	12.19
Big Muddy, Jackson Co.	6.35	31.50	55.25	6.90	2.02	12567		13.0
Bureau Co.						13025		13.48
Colchester	11.60	25.02	44.76	18.62			9848	10.19
Colchester Slack	5.30	25.45	38.15	31.10	1.20		9035	9.35
Collinsville, Madison Co.	9.20	45.89	31.57	13.34	5.34		10143	10.50
Dumferline Slack	9.64	28.86	39.48	22.02			9401	9.73
Duquoin Jupiter, Perry Co.	11.30	30.31	49.91	8.48	0.91		10710	11.08
Ellsworth, Macoupin Co.	9.26	42.22	42.17	6.35	2.62	12175		12.60
Gillespie, Macoupin Co.	12.61	30.58	45.27	11.54	1.45		9739	10.09
Girard, Macoupin Co.	9.70	34.39	45.76	10.15	3.49		9954	10.30
Girard, Macoupin Co.	8.90	32.25	42.89	15.96	8.10		10269	10.63
Heitz Bluff, St. Clair Co.	8.95	37.81	48.24	5.00	3.27		10332	10.69
Johnson's, St. Clair Co.	5.50	40.14	40.53	13.83	4.80	11723		12.10
Loose's, Sagamon Co.	10.71	37.62	45.07	6.60	2.39	11479		11.9
Mercer Co.						13123		13.58
Montauk Co.						12659		13.10
Mt. Olive, Macoupin Co.	10.38	36.68	46.10	6.84	3.53	11763		12.2
Oakland, St. Clair Co.	8.30	34.40	43.12	14.18	4.42		10395	10.76
Reinecke, St. Clair Co.	7.56	39.81	42.49	10.14	4.02	11720		12.1
Riverton, Sagamon Co.	11.06	37.94	42.98	8.02	3.27	11406		11.8
St. Clair	7.80	30.69	39.68	21.83	9.62		9261	9.58
St. Clair	10.25	33.10	41.79	14.86	6.92		10294	10.65
St. Clair	11.15	34.19	44.94	9.72	4.27		10647	11.02
St. Bernard	14.36	30.86	48.39	6.39	1.38		10080	10.44
St. John, Perry Co.	9.82	28.35	45.77	16.08	2.06		9765	10.10
St. John, Perry Co.	13.60	24.46	43.54	15.40	1.83		9828	10.18
Streator, LaSalle Co.	12.01	35.32	48.78	3.89	2.38		11403	11.80
Trenton, Clinton	13.34	30.39	51.96	4.31	0.92		10584	10.96
Trenton, Clinton	9.95	31.04	52.03	6.98	1.04		11245	11.68
Vulcan Nut, St. Clair Co.	7.44	30.86	45.09	16.61	1.32		9450	9.78
Vulcan Nut, St. Clair, Co.	10.30	27.91	48.99	12.80	0.71		10626	11.00
INDIANA.								
Block	3.50	32.50	63.00	1.00	0.98	14020		14.5
Block						13588		14.38
Caking						14146		14.64
Cannel						13097		13.56

TABLE OF AMERICAN COALS (*continued*).

COAL. Name or Lucality.	Constituents in Per Cent of Total Weight.					Fuel Value per Lb. of Coal.		
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	B. T. U. Calculated	B. T. U. by Calorimeter.	Theoretical Evaporation in lbs., from and at 212°.
INDIAN TERRITORY.								
Atoka	6.66	35.42	51.32	6.60	3.73		11088	11.47
Choctaw Nation	1.59	23.31	66.85	8.25	1.18		12789	13.23
IOWA.								
Good Cheer	10.85	30.32	31.38	27.45	7.32		8702	9.01
KENTUCKY.								
Caking						14391		14.89
Cannel						15198		16.76
Capnel						13360		13.84
Lignite						9326		9.65
MISSOURI.								
Bevier Mines							9890	10.24
MARYLAND.								
Cumberland						12226		12.65
George's Creek						13500		13.98
NEW MEXICO.								
Coal	2.35	35.53	50.24	11.88	0.61		11756	12.17
OHIO.								
Briar Hill, Mahoning Co.	2.47	31.83	64.25	1.45	0.56	13714		14.2
Hocking Valley	8.25	35.88	53.15	2.72	0.43	13414		13.9
PENNSYLVANIA.								
Anthracite						14199		14.70
Anthracite						13535		14.01
Anthracite						14221		14.72
Anthracite, Pea	2.04	6.36	78.41	13.19		12300		12.73
Anthracite, Buckwheat	3.88	3.84	81.32	10.96	0.67	12200		12.63
Cannel						13143		13.60
Connellsville						13368		13.84
Pittsburgh (av.)	1.50	35.34	54.94	7.92	1.97		13104	13.46
Pittsburgh Coking	1.43	30.22	61.87	6.48	1.35	14415		14.9
Youghiogheny	1.96	34.06	58.98	5.00			12936	13.39
Youghingheny	2.02	32.14	58.96	6.88	0.88		12600	13.03
Reynoldsville	1.20	27.12	65.88	5.80			12981	13.44
TENNESSEE.								
Glen Mary, Scott Co.	2.15	31.47	61.63	4.75	0.94		13167	13.63
TEXAS.								
Ft. Worth	14.42	30.03	42.53	13.02	1.47		9450	9.78
Ft. Worth	4.60	34.72	49.27	11.41	1.56		11403	11.80
Lignite						12962		13.41
WEST VIRGINIA.								
New River						14200		14.70
New River						13400		13.87

Classification of Coals.—Rankine classifies them as follows:

1. Anthracite, consisting almost wholly of carbon.
2. Semi-bituminous coal, having 70 to 80 per cent. of carbon.
3. Bituminous, caking coal, with 50 to 60 per cent. of carbon.
4. Cannel or long flaming coal, having 75 to 85 per cent. o carbon.
5. Lignite or brown coal, having 50 to 75 per cent. of carbon.

The 2d and 3d are used most for steam coals. No. 1 is foun principally in the Alleghany mountains, No. 2 in Maryland an Virginia, No. 3 in the Mississippi valley, No. 4 in Pennsylvani and Indiana, and No. 5 in Colorado and Texas.

Sizes and space occupied by coal, per ton of 2240 pound anthracite:

Lump	32.2 cu. ft.	Stove	34.8 cu.
Broken	33.9 "	Chestnut	35.7 "
Egg	34.5 "	Pea	36.7 "

The Value of Wood as Fuel Compared with Coal.—Two an a half pounds of dry wood are equal to one pound (average quality of soft coal, and the fuel value of the same weight of differen woods is very nearly the same,—that is, a pound of hickory i worth no more for fuel than a pound of pine, assuming both t be dry. If the value be measured by the weight, it is importan that the wood be dry, as each 10 per cent. of moisture or wate in the wood will detract about 12 per cent. from its value as a fuel.

The weight of one cord of different woods (air-dried) is a follows:

Hickory, or Hard Maple	4500 lbs
White Oak	3850 "
Beech, Red Oak, and Black Oak	3250 "
Poplar, Chestnut, and Elm	2350 "
Pine	2000 "

The fuel value of wood, as compared with coal, is about *follows:*

l air-dried Hickory, or Hard Maple, equal to 2000 lbs. coal.
l air-dried White Oak equal to . . . . 1725 " "
l air-dried Beech, Red Oak, or Black Oak
al to . . . . 1450 " "
l air-dried Poplar, Chestnut, or Elm equal to 1050 " "
l air-dried Average of Pine Wood equal to 925 " "

nparative value of different kinds of wood for fuel.

ark Hickory	100	Yellow Oak	60
t Hickory	95	Hard Maple	59
Oak	84	White Elm	58
Ash	77	Red Cedar	56
Vood	75	Wild Cherry	55
Oak	73	Yellow Pine	54
Hazel	72	Chestnut	52
-Tree	70	Yellow Poplar	51
ak	67	Butternut and White Birch	43
Beech	65	White Pine	30
Birch	62		

er Solid Fuels.—Sawdust and shavings are largely used in and have an evaporative power practically the same as an weight of wood of the same state of dryness. Spent tan vhen dry has considerable evaporative power. The refuse as works, known a breeze, has a high heat value, as has sse," the refuse of sugar cane. Peat, cotton stalks, straw, e also used to some extent. An approximate idea of the e value of some of these compared to good coal is given in le below.

RETIC EVAPORATING POWER OF SUBSTANCES FROM 212° F.

	12 lbs.	Tan (dry)	4 lbs.
ıt.	6 "	Cotton stalks	3 "
	4 "	Straw	2½ "

id Fuels—Petroleum.—The high evaporative power of um, about 21 pounds of water per pound of fuel, has led eat deal of experiment in its use for making steam. It has portant advantages, among which may be mentioned:

It is cleaner, having no ash residue, and is more easily han allowing a smaller number of men to handle a given horse-p of boilers. It gives a steadier fire, occupies for an equal nu of heat units about two-thirds as much space as coal, and be more readily managed in the matter of starting and stop fires in the boiler furnace. Moreover, it makes no cinders little or no smoke. With all these advantages it is the ques of relative cost of coal and oil at different points that determ the advisability of its use at those places. Coal at about $3.00 ton is about equal to petroleum at 2 cents per gallon, as fa the fuel cost for evaporating a pound of water is concerned. saving of labor, etc., must be calculated for each particular ca

Composition of Petroleum.—Analyses of many different pe leums give the following as the chemical composition:

Carbon	82 to 85 per cent.
Hydrogen	11 to 15 "
Oxygen	5 to 6 "

When distilled it gives off at different temperatures diffe products, each having distinctive properties. Some of the m common are:

Gasolene,	distilling	at about	140°–160° F.
Benzine	"	"	160°–200°
Naphtha	"	"	200°–250°
Kerosene	"	"	350°–450°
Oils used for lubrication			450° and above.

Weight of petroleum differs with its composition, but ma taken roughly as about eight-tenths that of water.

Gaseous fuels possess many of the advantages of petroleum use in boiler furnaces. The principal ones available are nat gas, illuminating gas, water gas, and producer gas. While relative proportions of the chemical constituents of natural differ considerably in the different parts of the country where gas is found, yet the following tables will give a fairly close of the composition of these gases. These tables are taken f the results of Mr. Emerson McMillan:

OSITION OF GASES—VOLUME AND WEIGHT.

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
	2.18	46.00	45.00	6.00
	92.60	40.00	2.00	3.00
e	0.50	6.00	45.00	23.50
	0.31	4.00	0.00	0.00
	0.26	0.50	4.00	1.50
	3.61	1.50	2.00	65.00
	0.34	0.50	0.50	0.00
	0.00	1.50	1.50	1.00
d	0.20	----	----	----
	100.00	100.00	100.00	100.00

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
	0.268	8.21	5.431	0.458
	90.383	57.20	1.931	1.831
le	0.857	15.02	76.041	25.095
	0.531	10.01	0.000	0.000
1	0.700	1.97	10.622	2.517
	6.178	3.75	3.380	69.413
	0.666	1.43	0.965	0.000
	0.000	2.41	1.630	0.686
id	0.417	-----	-----	-----
	100.000	100.000	100.000	100.000

ative evaporating values have been calculated on that 20 per cent. more air entering at a temperature lmitted to the fire-box than would just supply the gen necessary for perfect combustion, and also that e of the gas escaping from the boiler flue is 500° F.

	Natural Gas	Illuminating Gas.	Water Gas.	Producer Gas.
....	1000	1000	1000	1000
0 cu. ft ..	45.5	32	45.5	66
ıporated..	893	591	262	115

Compared with Coal.—Roughly, 30,000 cubic gas, 45,000 cubic feet of illuminating gas, 10,000 *vater gas, and 120,000* cubic feet of producer gas *porating power to* one ton of good coal.

CHAPTER VI.

AIR AND OTHER GASES.

Gases.—All liquids if heated to a sufficiently high temp ture reach a point at which their physical state changes, and th evaporate into the gaseous condition. In this condition most them are colorless and without odor. They exert a pressure all directions and are elastic to the highest degree. They acted upon by gravity just like bodies in the liquid and solid co ditions, and therefore have weight. Many substances exist nat rally in the gaseous state, although they may all be liquefied b subjecting them to a sufficiently low temperature and pressu Among the most important elementary gases are oxygen, nit gen, and hydrogen.

Perfect gases are those which follow what is known as the l of *Boyle* or *Mariotte*, viz.: If the temperature be kept constant, t volume occupied by a gas varies inversely as the pressure p upon it. Thus when a gas is compressed into half its origi bulk its pressure is double; when compressed into a third of i original bulk its pressure is trebled; when compressed into fourth of its original bulk its pressure is quadrupled; and ge rally the pressure varies inversely as the bulk into which the g is compressed. So in like manner, if the volume be doubled, t pressure is made one-half of what it was before,—the pressure i every case being reckoned from 0, or from a perfect vacuum.

Thus, if we take the average pressure of the atmosphere at 14 pounds on the square inch, a cubic foot of air, if suffered to exp into twice its bulk, by being placed in a vacuum measuring t *cubic feet, will have* a pressure of 7.35 pounds above a perf *vacuum, and also of* 7.35 pounds below the atmospheric press ı, if the cubic foot be compressed into a space of half a ɔot, the pressure will become 29.4 pounds above a perfect ı, and 14.7 above the atmospheric pressure. The specific of any one gas to that of another will not exactly con- the same ratio under different degrees of heat, and other ɜs of the atmosphere.

of Charles.—Perfect gases also follow this law, which is— olume of a gas at constant pressure is proportional to its ɜ temperature;" that is, to the temperature measured above ɔlute zero, which, it will be remembered, is 460° below the heit zero. The expansion in volume for a gas for each rise in temperature is found to be $\frac{1}{497}$ of its volume. There- find the volume at any temperature, having given the vol- any other temperature as 0° F., we have the following ıubtract 32 from the temperature and multiply the result !04. Add to this product and then multiply it by the 32° F. The result will be the volume at the temperature

ication of Boyle's and Charles' Laws.—Another way of ing the two laws is, that the product of pressure by vol- proportional to the Absolute Temperature of the gas. [The e temperature is the temperature or number of degrees the absolute zero.] If $p =$ the pressure at any tempera- F., and $v =$ the volume, while $p' =$ the pressure and $v' =$ at some other temperature, t'° F., then the above rule may ·essed as follows: $\frac{p \times v}{p' \times t'} = \frac{460 + t}{460 + t'}$. The number 460 is the of degrees which the absolute zero is below the Fahren- 'o.

ıple.—10 cubic feet of air at atmospheric pressure and 40° F. ıpressed by a pressure of 29.4 pounds per square inch, and perature when measured is found to be 50° F. What vol- es the air now occupy? Here $p = 14.7$ pounds per square $= 10$ cubic *feet*, $t = 40^\circ$ *F.*, $t' = 50^\circ$ F., and $p' = 29.4$ pounds *ıre inch. Substituting* these values we have

$\frac{14.7\times 10}{29.4\times v'}=\frac{460+40}{460+50}=\frac{500}{510}$. Solving this for v' we ha

$$v'=\frac{510\times 14.7}{500\times 29.4}=5.1 \text{ cubic feet.}$$

The following table gives the specific gravities and we cubic foot of a number of gases:

Gas.		Sp. gr.	Grammes per cubic centimetre.
Air		1.000	0.001293
Ammonia		0.597	0.000770
Carbon dioxide		1.529	0.001974
Carbon monoxide		0.967	0.001234
Chlorine		2.422	0.003133
Coal gas	from	0.340	0.000421
	to	0.450	0.000558
Cyanogen		1.806	0.002330
Hydrofluoric acid		2.370	0.002937
Hydrochloric acid		1.250	0.001616
Hydrogen		0.0696	0.000090
Hydrogen sulphide		1.191	0.001476
Marsh gas		0.559	0.000727
Nitrogen		0.972	0.001257
Nitric oxide, NO		1.039	0.001343
Nitrous oxide, N_2O		1.527	0.001970
Oxygen		1.105	0.001430
Sulphur dioxide		2.247	0.002785
Steam at 100° C.		0.469	0.000581

Examples of perfect gases are Air, Oxygen, Hydro Nitrogen, and all substances in the gaseous condition wl not in contact with the liquid from which they are pr

gen.—Oxygen enters into chemical combination ber of substances, in which it exists in a c

l state; it is by the application of heat, or of acids, to some of
substances containing it, that it is usually procured in the
ı of gas. Oxygen gas is the only one that can be breathed by
nals for any length of time with impunity. The power of at-
pheric air in supporting respiration is owing to the oxygen.
ygen combines with all the metals, and in this state they are
ed metallic oxides, depriving them of their metallic lustre, and
ng them an earthy or rusty appearance. Any of the metals
capable of combining with different proportions of oxygen.
e with one proportion are called *protoxides;* of two, (*binoxides.*)

itrogen.—Nitrogen gas is most easily described by including
y of its negative qualities. It has no taste; it unites with
gen in several proportions; it also unites with hydrogen.
ugh incapable of being breathed above its base, nitrogen is a
ponent portion of all animal substances; it is lighter than oxy-
. Nitrogen gas may be variously obtained. If the oxygen be
acted from the atmospheric air, this substance will remain, and
generally be very pure, unless the oxygen has been extracted
respiration. If iron filings and sulphur, moistened with water,
ut into a jar containing atmospheric air, this gas will in a day
wo be all the air that remains in the jar, as the oxygen will
absorbed by the iron and sulphur. Phosphorus or sulphuret
ime or potass, inclosed with common air in a jar, will produce
milar effect.

ydrogen.—Hydrogen, like oxygen and nitrogen, is invisible,
tic, and inodorous; but the last quality it seldom possesses, be-
se it is very seldom perfectly dry, and when it contains water
olution, like alkaline sulphurets, its odor is considerably fetid.
drogen with oxygen forms water; and it is by the decomposi-
ı of water that chemists obtain it in the greatest abundance
l purity. For this purpose iron filing or turnings, or granu-
d zinc, are put into a retort, and covered with sulphuric acid
ted with four times its weight in water. A violent effervescence
es, a large quantity of gas is evolved, and issuing from the
rt is collected in the usual manner by the pneumatic appa-

ratus. In this experiment the acid is not decomposed; it is oxygen of the water with which the acid is diluted that seizes u and oxidizes the metal, and the hydrogen, in the same portion water being thus disengaged, passes over in the state of gas. hydrogen obtained by using zinc is the purest, that obtained using iron generally containing some carbon.

Hydrogen combines with a larger quantity of oxygen than other body; its combustion, therefore, when mixed with oxyg produces a more intense heat than any other combustion.

It is the lightest of all known substances, having a weight cubic foot only one-sixteenth that of oxygen, one-fourteenth of nitrogen, and seven-hundredths that of air.

The flow of gases under pressure is taken up under the subj of air, which acts like other gases in this respect.

Air.

The atmosphere is known to extend at least 45 miles above earth. Its aggregate weight has been calculated at upwards 77,000,000,000 of tons, or equivalent to the weight of a solid gl of lead 60 miles in diameter. Hence, this enormous weight poses incessantly upon the earth's surface, and upon every obj animate or inanimate, solid, liquid, or aëriform. 100 cubic inc of air at the surface of the earth, when the barometer stands 34 inches, and at a temperature of 60° Fah., weigh about 31 gra being thus about 815 times lighter than water, and 11,065 ti lighter than mercury. The component parts of the air are ab 79 measures of nitrogen gas and 21 of oxygen; or, in other wo air consists of (by volume) oxygen, 21 parts; nitrogen, 79 pa (by weight) oxygen, 23 parts; nitrogen, 77 parts.

Now, since the air is possessed of weight, it must be evid that a cubic foot of air at the surface of the earth has to supp the weight of all the air directly above it; and that, therefore, *higher* we ascend in the atmosphere, the lighter will be the cu *ot of air; or,* in other words, the farther from the surface of rth the less will be the density of the air. At the height of ree and a half miles, it is known that the atmospheric air is only lf as dense as it is at the surface of the earth. From the nature f fluids, it follows that the atmosphere presses against any body th which it comes in contact — because fluids exert a pressure in ll directions — upwards, downwards, sidewise, and obliquely. Its rticles are so inconceivably minute, that they enter all substances, en liquids. It penetrates all the ramifications and innermost cesses of porous bodies, and is mixed up with and circulates in e blood of men and animals; and by the pressure of its supercumbent strata, it is urged through almost every substance. It is this circulation through the interior of the bodies of men and imals which counterbalances its outer pressure; because, if its eight were not neutralized, neither man nor beast could walk, nd would be as mute as statues of lead, and lips once closed could ever again be opened.

The amount of pressure of a column of air, whose base is one uare foot and whose altitude is the height of the atmosphere, as been found to be 2156 pounds avoirdupois, or very nearly 15 unds of pressure on every square inch. Consequently, it is common to state the pressure of the atmosphere as equal to 15 pounds n the square inch. If any other gaseous body or vapor — such as eam — exerts a pressure equivalent to 15 pounds on the square ch, then the force of that vapor is said to be equal to one atmoshere. If the vapor be equal to 30 pounds on every square inch, en it is equal to two atmospheres, and so on; consequently, the mospheric pressure is capable of supporting about 30 inches of ercury, or a column of water 34 feet high.

It is known that the pressure of the atmosphere is not constant, ven at the same place. At the equator, the pressure is nearly onstant, but is subject to great changes in high latitudes. In ome countries the pressure of the atmosphere varies so much as o support a column of mercury so low as 28 inches, and at other mes so high *as 31, the mean being 29·5*; thus making the average *ressure between 14 and 15 pounds* on the square inch. But in scientific books, generally, the pressure is understood, in ro numbers, to be 15 pounds; so that a pressure exerted equal to 2, 3, 4, etc., atmospheres means such a pressure as would supp 30, 60, 90, 120, eto., inches in a perpendicular column, or 15, 45, 60, etc., pounds on every square inch.

TABLE

OF ALTITUDES ABOVE SEA-LEVEL, AND THE CORRESPONDING AT PHERIC PRESSURES, DEDUCED FROM THE OBSERVATIONS OF THE HA DEN EXPEDITION TO THE ROCKY MOUNTAINS.

Location.	Altitude in Feet.	Pressu of the Atmosph
Altoona, Pa.	1,168·	14·08
Cairo, Ill.	291·23	14·56
Cheyenne, Wy. Ter.	6,075·28	11·48
Cincinnati, O.	440·	14·46
Cresson, Pa.	2,000·	13·64
Denver, Col.	5,196·58	11·94
Golden City, Col.	5,728·98	11·67
Lake Champlain	100·84	14·64
" Erie	573·08	14·39
" Huron	589·99	14·38
" Michigan.	589·15	14·39
" Ontario.	249·99	14·56
Louisville, Ky.	404·	14·48
Mt. Lincoln, Col.	14,296·66	7·06
New Albany, Ind.	379·75	14·5
Ogden, Utah	4,303·3	12·42
Omaha, Neb.	977·9	14·18
Pike's Peak, Col.	14,148·66	7·1
Pittsburg, Pa.	699·2	14·33
Rock Island, Ill.	566·68	14·40
St. Louis, Mo.	429·29	14·17
Terre Haute, Ind.	485·55	14·44

The pressure of the air differs at different altitudes; at 7 m *above the surface* of the earth, the air is 4 times lighter at the surface; at 14 miles it is 16 times lighter; and at 21 s it is 64 times lighter. It requires 13.817 cubic feet of air ake one pound; consequently, one cubic foot of air at the ace of the earth weighs 507 grains, or about 1¼ ounces avoir- ois; but under a pressure of 5½ tons to the square inch, air mes as dense, and would weigh as much per cubic foot, as r.

The Barometer.

he **barometer** is an instrument used for observing the press- and elasticity, or variations in density, of the atmosphere. ssential part is a well-formed glass tube, closed at one end, ectly clear and free from flaws, 33 or 34 inches long, of uniform , filled with pure mercury, and inverted; the open end being rted in a cup partly filled with the same metal, so that the cury in the tube may be supported by atmospheric pressure. he more elaborate patterns the cup is made of leather arranged at it can be raised or lowered by a milled screw so as to bring level of mercury in the cup even with the zero on the scale. upper end of the mercury column is read by a sighting piece ying a vernier.

hen changes in the weight of the atmosphere take place ually they are imperceptible to human sensation; and if it not for this instrument it would be impossible to estimate rately atmospheric conditions. If, in fine, clear weather, a -storm is approaching, the increasing humidity of the atmos- e will be noted by the fall of the barometer long before it will erceived by ordinary observers. Hence, the condition of the meter is an indication of not only the weather at the time, of that which is to follow during the course of several hours. in a constant state of variation, governed by the condition of air. The mercury in the barometer stops falling at 30 inches a-level.

he pressure *of the atmosphere at* sea-level is 14.7 pounds per *re inch, pressing equally in all* directions. This has been ascertained from the following illustration. Because the heig of a column of air of one square inch area exactly balances a c umn of mercury of the same area 30 inches in height, and also column of water 33.86 feet in height, it follows that a column air, 30 inches of mercury, and 33.86 feet of water weigh the sa and since the last two weigh respectively 14.7 pounds per squ inch, a full column of air must weigh the same. A cubic foot water evaporated under a pressure of one atmosphere, or pounds per square inch, occupies a space of 1700 cubic feet.

TABLE

SHOWING THE WEIGHT OF THE ATMOSPHERE PER SQUARE INCH COR SPONDING WITH DIFFERENT HEIGHTS OF THE BAROMETER.

Barometer in Inches.	Atmosphere in Pounds.	Barometer in Inches.	Atmosphere in Pounds.	Barometer in Inches.	Atmosphere in Pounds.
28·0	13·72	29·1	14·26	30·1	14·75
28·1	13·77	29·2	14·31	30·2	14·80
28·2	13·82	29·3	14·36	30·3	14·85
28·3	13·87	29·4	14·41	30·4	14·90
28·4	13·92	29·5	14·46	30·5	14·95
28·5	13·97	29·6	14·51	30·6	15·00
28·6	14·02	29·7	14·56	30·7	15·05
28·7	14·07	29·8	14·61	30·8	15·10
28·8	14·12	29·9	14·66	30·9	15·15
28·9	14·17	30·0	14·70	31·	15·19
29·0	14·21				

The Aneroid Barometer is a portable form and operates up an entirely different principle. In consists of a hollow cylind very short in proportion to its diameter, and made of very th metal corrugated in rings concentric with the axis of the cylind The air is exhausted from the inside of the cylinder, and its en are therefore pressed toward each other by the pressure of t atmosphere. The greater this pressure the more the ends a *pressed together,* and the motion produced by pressure is mul *plied and read* by a needle working over a graduated circ 'hile this form of barometer is more convenient, it regis- ıtmospheric pressure less accurately.

ırement of Heights by Barometer.—By the following height above sea level of any place may be obtained, it ly necessary to read a barometer at that place:

	Height in feet above sea level.	Reading of Barometer in inches, temp. 60° F.	Height in feet above sea level.
	0	27	2935
	469	26.5	3432
	945	26	3983
	1430	25.5	4519
	1923	25	5069
	2422	24.5	5627

culate the heights for readings between those in the table following rule: Multiply the number in the following responding to the temperature by 30 minus the reading .rometer in inches, and divide the product by 30 plus the ɪr reading. The result will be the height above the sea

	Multiplier.	Deg. Fah.	Multiplier.
	49445	55	55178
	49928	60	55761
	50511	65	56344
	51094	70	56927
	51677	75	57511
	52261	80	58094
	52844	85	58677
	53428	90	59260
	54011	95	59844
	54595	100	60427

ɜr method of finding the height by using the ther- will be found described on page 134.

e of Air at Various Temperatures.—If a cubic inch of ' F. is heated *at constant pressure,* it will occupy volumes *t temperatures as given* in the table on pp. 122 and 123.

TABLE

SHOWING THE RELATIVE VOLUMES OF AIR AT VARIOUS TEMPERA

Temp. Fah.	Volume in Cubic In.	Temp. Fah.	Volume in Cubic In.	Temp. Fah.	Volume in Cubic In.	Temp. Fah.	Vol Cu
—49	834·7	— 6	922·5	37	1010·2	80	10
—48	836·7	— 5	924·5	38	1012·2	81	10
—47	838·8	— 4	926·5	39	1014·3	82	11
—46	840·8	— 3	928·6	40	1016·3	83	11
—45	842·8	— 2	930·6	41	1018·4	84	11
—44	844·9	— 1	932·7	42	1020·4	85	11
—43	846·9	— 0	934·7	43	1022·4	86	11
—42	849·0	1	936·7	44	1024·5	87	11
—41	851·0	2	938·8	45	1026·5	88	11
—40	853·1	3	940·8	46	1028·6	89	11
—39	855·1	4	942·9	47	1030·6	90	11
—38	857·1	5	944·9	48	1032·7	91	11
—37	859·2	6	947·0	49	1034·7	92	11
—36	861·2	7	949·0	50	1036·7	93	11
—35	863·3	8	951·0	51	1038·8	94	11
—34	865·3	9	953·1	52	1040·8	95	11
—33	867·3	10	955·1	53	1042·9	96	11
—32	869·4	11	957·1	54	1044·9	97	11
—31	871·4	12	959·2	55	1046·9	98	11
—30	873·5	13	961·2	56	1049·0	99	11
—29	875·5	14	963·3	57	1051·0	100	11
—28	877·6	15	965·3	58	1053·1	101	11
—27	879·6	16	967·3	59	1055·1	102	11
—26	881·6	17	969·4	60	1057·1	103	11
—25	883·7	18	971·4	61	1059·2	104	11
—24	885·7	19	973·5	62	1061·2	105	11
—23	887·8	20	975·5	63	1063·3	106	11
—22	889·8	21	977·6	64	1065·3	107	11
—21	891·8	22	979·6	65	1067·3	108	11
—20	893·9	23	981·6	66	1069·4	109	11
—19	895·9	24	983·7	67	1071·4	110	11
—18	898·0	25	985·7	68	1073·5	111	11
—17	900·0	26	987·8	69	1075·5	112	11
—16	902·0	27	989·8	70	1077·6	113	11
—15	904·1	28	991·8	71	1079·6	114	11
—14	906·1	29	993·9	72	1081·6	115	11
—13	908·2	30	995·9	73	1083·7	116	11
—12	910·2	31	998·0	74	1085·7	117	11
—11	912·2	32	1000·0	75	1087·8	118	11
—10	914·3	33	1000·2	76	1089·8	119	11
— 9	916·3	34	1004·1	77	1091·8	120	11
8	918·4	35	1006·1	78	1093·9	121	11
	920·4	36	1008·2	79	1095·9	122	1

TABLE — (*Continued.*)

p.	Volume in Cubic In.	Temp. Fah.	Volume in Cubic In.	Temp. Fah.	Volume in Cubic In.	Temp. Fah.	Volume in Cubic In.
3	1185·7	152	1244·9	180	1302·0	208	1359·2
4	1187·8	153	1246·9	181	1304·1	209	1361·2
5	1189·8	154	1249·0	182	1306·1	210	1363·3
6	1191·8	155	1251·0	183	1308·2	211	1365·3
7	1193·9	156	1253·0	184	1310·2	212	1367·3
8	1195·9	157	1255·1	185	1312·2	213	1369·4
9	1198·0	158	1257·1	186	1314·3	214	1371·4
0	1200·0	159	1259·2	187	1316·3	215	1373·5
1	1202·0	160	1261·2	188	1318·4	216	1375·5
2	1204·1	161	1263·3	189	1320·4	217	1377·5
3	1206·1	162	1265·3	190	1322·4	218	1379·6
4	1208·2	163	1267·3	191	1324·5	219	1381·6
5	1210·2	164	1269·4	192	1326·5	220	1383·7
6	1212·2	165	1271·4	193	1328·6	230	1404·1
7	1214·3	166	1273·5	194	1330·6	240	1424·5
8	1216·3	167	1275·5	195	1332·6	250	1444·9
9	1218·4	168	1277·5	196	1334·7	260	1465·3
0	1220·4	169	1279·6	197	1336·7	270	1485·7
1	1222·4	170	1281·6	198	1338·8	280	1506·1
2	1224·5	171	1283·7	199	1340·8	290	1526·5
3	1226·5	172	1285·7	200	1342·9	350	1546·9
4	1228·6	173	1287·8	201	1344·9	400	1751·0
5	1230·6	174	1289·8	202	1346·9	500	1955·1
6	1232·7	175	1291·8	203	1349·0	600	2159·2
7	1234·7	176	1293·9	204	1351·0	700	2363·3
8	1236·7	177	1295·9	205	1353·1	800	2567·4
9	1238·8	178	1298·0	206	1355·1	900	2771·5
0	1240·8	179	1300·0	207	1357·1	1000	2975·6
1	1242·9						

low of Air or Gases through an Orifice.—Prof. Peabody gives following rules:

. If the absolute pressure (above a vacuum) of the escaping gas ore than twice the atmospheric pressure, *multiply* the area of the ice in square inches by .53 and then by the absolute pressure of gas reservoir, and divide the product by the square root of the olute temperature [460 plus the reading of the thermometer].

. If the absolute pressure of the reservoir is less than twice atmospheric pressure, subtract the atmospheric pressure from *reservoir pressure, multiply* the difference by the atmospheric *sure, extract the square root of* this product, multiply by th area of orifice in square inches, multiply also by 1060, and divide by the absolute temperature.

The flow of gases through pipes will be found treated the Transmission of Power by Compressed Air.

TABLE

SHOWING THE FORCE OF THE WIND IN POUNDS PER SQUARE F DIFFERENT VELOCITIES.

Miles per Hour.	Feet per Second.	Force per Square Foot Pound.	
1	1·47	0·005	Hardly perceptil
2	2·93	0·020	Just perceptible.
3	4·4	0·044	
4	5·87	0·079	Gentle, pleasant
5	7·33	0·123	
6	8·8	0·177	
7	10·25	0·241	
8	11·75	0·315	Pleasant, brisk g
9	13·2	0·400	
10	14·67	0·492	
12	17·6	0·708	
14	20·5	0·964	
15	22·00	1·107	
16	23·45	1·25	
18	26·4	1·55	Very brisk.
20	29·34	1·968	
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	
45	66·01	9·963	Very high.
50	73·35	12·30	
55	80·7	14·9	
60	88·02	17·71	Storm or tempes
65	95·4	20·85	
70	102·5	24·1	Great storm.
75	110·	27·7	Hurricane.
80	*117·36*	31·49	
	146·66	50·	Tornado.

Horse-Power of Wind Storms.

It is asserted that severe wind storms exert a pressure of from 5 to 30 lbs. per square foot, and travel from 50 to 70 miles per our. Assuming that the pressure is 30 lbs. per square foot, or of a pound per square inch, with a speed of 66 miles per hour, hen, as there are 27,878,400 square feet, or 4,014,489,600 square nches in a square mile, if the pressure of the storm was exerted or the height of half a mile, it will give an area of 2,007,244,800 quare inches for each mile in width upon which the storm acts.

Rule *for finding the horse-power of wind storms.*

Multiply the area acted on in inches by the pressure in lbs. per quare inch; then multiply this product by the speed in feet per minute, and divide by 33,000. The quotient will be the horse-ower of the storm.

Example.—2,007,244,800 square inches × .2 lb. pressure × 800 feet ÷ 33,000, which gives as a result 70,557,700 horse-ower developed for each mile of breadth of the track of the storm. o produce the same horse-power with improved engines consum-ng but two pounds of coal per hour per horse-power, would re-uire 63,000 gross tons of coal per hour.

Windmills.—The following table will give an idea of the capac-ty of windmills when the velocity of the wind is 16 miles per hour:

iam. of wheel.	Revolutions per minute.	Gallons of water per minute raised to a height of—						Equiv. horse-power.
		25 feet.	50 feet.	75 feet.	100 feet.	150 feet.	200 feet.	
3½ feet.	75	6	3	......	......	......	......	.04
10 "	65	20	10	6.6	5.0	......	......	.12
12 "	60	34	17	11.3	8.5	5.7	......	.21
14 "	55	46	23	15.3	11.5	7.3	5.	.28
16 "	50	65	33	22.0	16.5	11.0	8.	.41
20 "	40	125	63	42.0	41.1	21.0	15.	.77

Vapors.

The *mechanical properties of vapor* are similar to those of *ses in general.* *When a vapor* or gas is contained in a clos vessel, the inner surface of the vessel will sustain a pressure aris from the elasticity of the fluid. This pressure is produced by mutual repulsion of the particles, which gives them a tendency fly asunder, and causes the mass of the fluid to exert a force te ing to burst any vessel within which it is confined. This press is uniformly diffused over every part of the surface of the ves in which such fluid is contained. It is to this quality that all t mechanical power of steam is due.

It is well known from common observation, that liquids, if i confined in close vessels, become transformed into a condition sembling gases at ordinary temperatures, and then disappe This transformation takes place in nearly all liquids more or l rapidly at ordinary temperatures, though in some it takes pl at a very low temperature and at an imperceptible rate of ev oration; the lighter the specific gravity, the more rapidly it w disappear.

Vapors differ from perfect gases in not following Boyle's la All gases when near their point of liquefaction cease to foll this law and become vapors.

TABLE

SHOWING THE PRESSURE OF SATURATED VAPOR IN ATMOSPHERES, ACCORDING TO ZEUNER.

ATMOSPHERES.	TEMPERATURE IN DEGREES FAH., WATER.	ATMOSPHERES.	TEMPERATURE I DEGREES FAH., WATER.
1	212°	6	318·5°
2	248°	7	329·5°
3	272°	8	339·0°
4	291°	9	348·0°
5	306°	10	357·0°

TABLE

OWING THE PRESSURE AND TEMPERATURE OF THE VAPORS OF WATER FROM 32° TO 400° FAH.

Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.	Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.
32	0·006	0·09	0·00	73	0·026	0·38	0·02
33	0·006	0·09	0·00	74	0·027	0·40	0·01
34	0·006	0·09	0·01	75	0·028	0·41	0·02
35	0·007	0·10	0·00	76	0·029	0·43	0·03
36	0·007	0·10	0·01	77	0·031	0·46	0·00
37	0·007	0·11	0·01	78	0·031	0·46	0·01
38	0·008	0·12	0·00	79	0·032	0·47	0·00
39	0·008	0·12	0·01	80	0·032	0·47	0·02
40	0·009	0·13	0·00	81	0·033	0·49	0·01
41	0·009	0·13	0·01	82	0·034	0·50	0·03
42	0·009	0·14	0·00	83	0·036	0·53	0·01
43	0·009	0·14	0·01	84	0·037	0·54	0·03
44	0·010	0·15	0·00	85	0·039	0·57	0·03
45	0·010	0·15	0·01	86	0·041	0·60	0·02
46	0·011	0·16	0·00	87	0·042	0·62	0·01
47	0·011	0·16	0·01	88	0·043	0·63	0·02
48	0·011	0·17	0·00	89	0·044	0·65	0·03
49	0·011	0·17	0·01	90	0·046	0·68	0·03
50	0·012	0·18	0·00	91	0·048	0·71	0·01
51	0·012	0·18	0·01	92	0·049	0·72	0·02
52	0·013	0·19	0·01	93	0·050	0·74	0·02
53	0·013	0·20	0·01	94	0·052	0·76	0·05
54	0·014	0·21	0·00	95	0·055	0·81	0·03
55	0·014	0·21	0·01	96	0·057	0·84	0·01
56	0·015	0·22	0·02	97	0·058	0·85	0·05
57	0·016	0·24	0·00	98	0·061	0·90	0·00
58	0·016	0·24	0·01	99	0·061	0·90	0·03
59	0·017	0·25	0·01	100	0·063	0·93	0·04
60	0·018	0·26	0·00	101	0·066	0·97	0·01
61	0·018	0·26	0·00	102	0·067	0·98	0·03
62	0·018	0·26	0·02	103	0·069	1·01	0·05
63	0·019	0·28	0·01	104	0·072	1·06	0·03
64	0·020	0·29	0·00	105	0·074	1·09	0·06
65	0·020	0·29	0·02	106	0·078	1·15	0·01
66	0·021	0·31	0·01	107	0·079	1·16	0·02
67	0·022	0·32	0·02	108	0·080	1·18	0·04
68	0·023	0·34	0·00	119	0·083	1·22	0·04
69	0·023	0·34	0·01	110	0·086	1·26	0·03
70	0·024	0·35	0·00	111	0·088	1·29	0·05
71	0·024	0·35	0·02	112	0·091	1·34	0·03
72	0·025	0·37	0·01	113	0·093	1·37	0·03

TABLE — (*Continued.*)

Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.	Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Diff- enc
114	0·095	1·40	0·07	157	0·300	4·41	0·09
115	0·100	1·47	0·03	158	0·306	4·50	0·03
116	0·102	1·50	0·04	159	0·308	4·53	0·14
117	0·105	1·54	0·03	160	0·318	4·67	0·11
118	0·107	1·57	0·08	161	0·325	4·78	0·19
119	0·112	1·65	0·03	162	0·338	4·97	0·10
120	0·114	1·68	0·04	163	0·345	5·07	0·12
121	0·117	1·72	0·06	164	0·353	5·19	0·12
122	0·121	1·78	0·04	165	0·361	5·31	0·14
123	0·124	1·82	0·05	166	0·371	5·45	0·12
124	0·127	1·87	0·04	167	0·379	5·57	0·02
125	0·130	1·91	0·09	168	0·387	5·69	0·13
126	0·136	2·00	0·04	169	0·396	5·82	0·13
127	0 139	2·04	0·05	170	0·405	5·95	0·15
128	0·142	2·09	0·06	171	0·415	6·10	0·15
129	0·146	2·15	0·05	172	0·425	6·25	0·16
130	0·150	2·20	0·06	173	0·436	6·41	0·13
131	0·154	2·26	0·06	174	0·445	6·54	0·15
132	0·158	2·32	0·06	175	0·455	6·69	0·16
133	0·162	2·38	0·06	176	0·466	6·85	0·15
134	0·166	2·44	0·09	177	0·476	7·00	0·15
135	0·172	2·53	0·04	178	0·488	7·15	0·21
136	0·175	2·57	0·09	179	0·501	7·36	0·18
137	0·181	2·66	0·03	180	0·513	7·54	0·12
138	0·183	2·69	0·12	181	0·521	7·66	0·15
139	0·191	2·81	0·07	182	0·531	7·81	0·17
140	0·196	2·88	0·06	183	0·543	7·98	0·19
141	0·200	2·94	0·07	184	0·556	8·17	0·19
142	0·205	3·01	0·08	185	0·569	8·36	0·18
143	0·210	3·09	0·10	186	0·581	8·54	0·18
144	0·217	3·19	0·04	187	0·593	8·72	0·17
145	0·220	3·23	0·09	188	0·605	8·89	0·19
146	0·226	3·32	0·08	189	0·618	9·08	0·21
147	0·231	3·40	0·10	190	0·631	9·29	0·21
148	0·238	3·50	0·10	191	0·646	9·50	0·22
149	0·245	3·60	0·09	192	0·661	9·72	0·22
150	0·251	3·69	0·02	193	0·676	9·94	0·22
151	0·259	3·81	0·09	194	0·691	10·16	0·20
152	0·265	3·90	0·08	195	0·705	10·36	0·21
153	0·271	3·98	0·11	196	0·719	10·57	0·22
154	0·278	4·09	0·10	197	0·734	10·79	0·22
155	*0·285*	4·19	0·06	198	0·749	11·01	0·22
156	*0·289*	4·25	0·16	199	0·764	11·23	0·22

TABLE — (*Continued.*)

Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.	Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.
0·770	11·45	0·12	243	1·794	26·37	0·47
0·787	11·57	0·25	244	1·826	26·84	0·49
0·804	11·82	0·43	245	1·859	27·33	0·50
0·833	12·25	0·25	246	1·893	27·83	0·51
0·850	12·50	0·24	247	1·928	28·34	0·50
0·867	12·74	0·27	248	1·962	28·84	0·52
0·885	13·01	0·28	249	1·997	29·36	0·51
0·904	13·29	0·28	250	2·032	29·87	0·53
0·923	13·57	0·28	251	2·068	30·40	0·53
0·942	13·85	0·28	252	2·104	30·93	0·54
0·961	14·13	0·29	253	2·141	31·47	0·56
0·981	14·42	0·28	254	2·179	32·03	0·57
1·000	14·77	0·30	255	2·217	32·60	0·56
1·020	15·00	0·29	256	2·256	33·16	0·56
1·040	15·29	0·31	257	2·294	33·72	0·59
1·061	15·60	0·32	258	2·334	34·31	0·59
1·083	15·92	0·31	259	2·374	34·90	0·60
1·104	16·23	0·31	260	2·415	35·50	0·60
1·125	16·54	0·32	261	2·456	36·10	0·62
1·147	16·86	0·32	262	2·498	36·72	0·63
1·169	17·18	0·33	263	2·541	37·35	0·63
1·191	17·51	0·35	264	2·584	37·98	0·64
1·215	17·86	0·34	265	2·627	38·62	0·64
1·238	18·20	0·34	266	2·671	39·26	0·67
1·261	18·54	0·35	267	2·716	39·93	0·66
1·285	18·89	0·35	268	2·761	40·59	0 67
1·309	19·24	0·37	269	2·807	41·26	0·69
1·334	19·61	0·37	270	2·854	41·95	0·69
1·359	19·98	0·38	271	2·901	42·64	0·71
1·385	20·36	0·44	272	2·949	43·35	0·71
1·415	20·80	0·40	273	2·997	44·06	0·72
1·442	21·20	0·39	274	3·046	44·78	0·75
1·469	21·59	0·42	275	3·097	45·53	0·73
1·497	22·01	0·41	276	3·147	46·26	0·75
1·525	22·42	0·41	277	3·198	47·01	0·77
1·553	22·83	0·43	278	3·250	47·78	0·77
1·582	23·26	0·44	279	3·303	48·55	0·80
1·612	23·70	0·42	280	3·357	49·35	0·79
1·641	24·12	0·43	281	3·411	50·14	0·81
1·670	24·55	0·44	282	3·466	50·95	0·81
1·700	24·99	0·45	283	3·521	51·76	0·81
1·731	25·45	0·45	284	3·576	52·57	0·82
1·762	25·90	0·47	285	3·632	53·39	0·84

TABLE — (*Continued.*)

Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.	Differences.	Temp. Fah.	Pressures in Atmospheres.	Pressures in Lbs. per Sq. Inch.
286	3·689	54·23	0·85	329	6·945	102·09
287	3·747	55·08	0·87	330	7·043	103·53
288	3·806	55·95	0·88	331	7·141	104·97
289	3·866	56·83	0·88	332	7·239	106·41
290	3·926	57·71	0·90	333	7·338	107·87
291	3·987	58·61	0·91	334	7·437	109·32
292	4·049	59·52	0·93	335	7·536	110·78
293	4·112	60·45	0·92	336	7·638	112·28
294	4·175	61·37	0·94	337	7·741	113·79
295	4·239	62·31	0·96	338	7·846	115·34
296	4·304	63·27	0·97	339	7·952	116·89
297	4·370	64·24	0·98	340	8·060	118·48
298	4·437	65·22	1·00	341	8·169	120·08
299	4·505	66·22	1·02	342	8·279	121·70
300	4·574	67·24	1·01	343	8·389	123·32
301	4·643	68·25	1·02	344	8·500	124·95
302	4·712	69·27	1·03	345	8·612	126·60
303	4·782	70·30	1·04	346	8·724	128·24
304	4·853	71·34	1·06	347	8·838	129·92
305	4·925	72·40	1·07	348	8·953	131·61
306	4·998	73·47	1·09	349	9·070	133·33
307	5·072	74·56	1·10	350	9·189	135·08
308	5·147	75·66	1·12	351	9·310	136·86
309	5·223	76·78	1·13	352	9·433	138·67
310	5·300	77·91	1·16	353	9·556	140·47
311	5·379	79·07	1·16	354	9·680	142·30
312	5·458	80·23	1·18	355	9·804	144·12
313	5·538	81·41	1·19	356	9·929	145·96
314	5·619	82·60	1·20	357	10·055	147·81
315	5·701	83·80	1·22	358	10·182	149·68
316	5·784	85·02	1·22	359	10·311	151·57
317	5·867	86·24	1·24	360	10·442	153·50
318	5·951	87·48	1·23	361	10·575	155·45
319	6·035	88·71	1·27	362	10·710	157·44
320	6·121	89·98	1·28	363	10·847	159·45
321	6·208	91·26	1·29	364	10·985	161·48
322	6·296	92·55	1·31	365	11·123	163·51
323	6·385	93·86	1·32	366	11·262	165·55
324	6·475	95·18	1·34	367	11·401	167·59
325	6·556	96·42	1·35	368	11·542	169·67
326	6·658	97·87	1·37	369	11·684	171·75
327	6·751	99·24	1·40	370	11·829	173·89
328	6·846	100·64	1·45	371	11·976	176·05

CHAPTER VII.

WATER.

Pure water is composed of hydrogen and oxygen in the prortions of two measures of hydrogen to one of oxygen, or one rt of hydrogen to 8 of oxygen; or oxygen, 89 parts by weight, d by measure 1 part; hydrogen, by weight, 11 parts, and by asure, 2 parts; but pure water is not attainable, nor is it to be nd in the laboratory of the chemist. Fortunately, however, re water is not necessary, nor even desirable, for either houseld or manufacturing purposes; because the presence of air and her gases adds very materially to the ease with which steam ay be generated, while the ammonia, which most water contains, proves it for manufacturing purposes.

The specific gravity of all waters is not the same. Sea water ries from 1·0269 to 1·0285, the mean being 1·0277, thus requirg 34·9741 cubic feet of sea water to make one ton, and about feet of fresh water. Water is heavier at night than during the y, owing to the higher temperature of the air in the daytime, hich makes the water less dense.

Water at the temperature of its maximum density is taken as e standard of specific gravity for solids and liquids.

General Properties of Water.—It is tasteless, odorless, and lorless, a poor conductor of heat and electricity and practically compressible. It absorbs most gases readily and dissolves a vast mber of solids and liquids. It exists in nature in all three physl conditions, solid, liquid, and gaseous, and is readily changed m ice into water and steam by the application of heat.

If we take a *water* *thermometer* and expose it to the cold, we *ll observe the following curious* phenomenon. The liquid will gradually descend until it reaches the temperature of 39.2° F at this point the contraction will cease; and, although the acting on the bulb is far below this point, the liquid will g ually ascend until it reaches 32° Fah., or freezing point, wh will solidify. The point at which the liquid commences to as is called its "point of maximum density."

One of the most curious phenomena connected with w before and after freezing, may be demonstrated as follows: Ta tall jar and fill it with water, say at 60° Fah.; at the top of jar fix a small mercurial thermometer, and another one at bottom; then place the jar at rest, exposed to the cold. The l thermometer will be observed to fall more rapidly than the one, until it reaches 39·2° Fah., when it will remain station The top thermometer will now fall, and continue to do so the water freezes; the bottom thermometer still remaining at 3 Fah. These effects are easily explained: the particles of w at the top being exposed to the cold, decrease in temperature, becoming denser, and fall to the bottom, their places being t up by warmer particles, which in their turn undergo the s change, until the whole volume has completely circulated, attained a temperature of 39·2° Fah. The particles now, ins of becoming denser, actually expand, and so remain at the until a thin layer of ice is formed. This is exactly what t place in our lakes and ponds during every frost; the circula continues until the whole mass attains the temperature of 3 Fah., when it is gradually and finally arrested; a thin laye ice is then formed at the top, acting as a cloak to the inte which, remaining always at 39·2° Fah., preserves the animals fishes from the action of intense cold.

Were it not for this fact, our lakes and rivers would al frozen at the bottom, and, as water is a bad conductor of they would in time be converted into a solid block of ice, w would defy the hottest rays of a tropical sun to melt. Thu *see that such* a wise provision of Nature depends entirely o *apparent exception* to a universal law, which is so slight t equires the most delicate experiments to detect it. The freezing oint of a liquid is almost invariably the same as its melting oint; that is, if we cool a liquid below its melting point, it will ecome solid. There are, of course, many exceptions to this, and ven water has been known to be cooled down to 4° Fah. without reezing. To effect this, however, water most be kept perfectly till, as, with the least vibration, congelation commences, and the emperature will instantly rise to zero.

When a substance solidifies or freezes, there is always a change f volume, which usually is a contraction; but, in the case of water, n expansion takes place. The expansion of water at the freezing oint is by no means gradual, but takes place almost instantaneusly, and the amount of force exerted at the time is enormous. t has been demonstrated by actual experiments, that in freezing, ater exerts a pressure of about 30,000 lbs. per square inch, which ar surpasses the strain that any of our machinery could bear.

TABLE

HOWING THE BOILING POINT FOR FRESH WATER AT DIFFERENT ALTITUDES ABOVE SEA-LEVEL.

Boiling Point in Deg. Fah.	Altitude above Sea-Level in Feet.	Boiling Point in Deg. Fah.	Altitude above Sea-Level in Feet.	Boiling Point in Deg. Fah.	Altitude above Sea-Level in Feet.
184°	15,221	195°	9,031	206°	3,115
185	14,649	196	8,481	207	2,589
186	14,075	197	7,932	208	2,063
187	13,498	198	7,381	209	1,539
188	12,934	199	6,843	210	1,025
189	12,367	200	6,304	211	512
190	11,799	201	5,764	212	Sea-Level = 0
191	11,243	202	5,225		
192	10,685	203	4,697	Below Sea-Level	
193	10,127	204	4,169	213	511
194	9,579	205	3,642		

Specific Heat of Water.—Water has the greatest specific hea of all known substances except bromine and hydrogen, and i taken as the standard of specific heat for all liquids and solid The specific heat of ice is one-half that of water, or .5

Water boils in the open air, at sea-level, at 212° F.; and i vacuum at 88° F. The less the pressure of the atmosphere, th lower is the temperature at which water will boil.

By observing the boiling-point of water with a thermometer two different places we can measure with a fair degree of accura their difference in height.

Salt water boils at a higher temperature than fresh, owing to i greater density, and because the boiling-point of water is increas by any substance that enters into chemical combination with i Mud and other substances, so long as they are kept in mechanic solution, will not increase the boiling-point of water; when the substances settle, and burn to the interior of the boilers, the boi ing-point will be increased. The density of water decreases as th temperature increases, since heat destroys cohesion and expand the particles, causing them to occupy greater space. The pow of water to hold chemical substances, such as salts of lime, in sol tion, decreases as the temperature increases; from this it follo that boilers carrying high-pressure steam form more scale th those working at low temperatures.

Decomposition of Water.—By an electric current from t or more battery cells water may be decomposed into its constit ents, oxygen and hydrogen. By filling a glass and inverting while filled in the vessel of water in which the terminals of th electric circuit are placed, we can collect the bubbles of gas, eith oxygen or hydrogen, according to which terminal we place th inverted glass over. [Care must be taken in handling the hydro gen, as it is explosive and any considerable quantity is liable t do damage.]

We can recombine the two elements to form water [in the for of steam] by burning hydrogen in a jet surrounded by a jar o *oxygen.*

WEIGHT OF WATER AT DIFFERENT TEMPERATURES.

EMPERATURE, FAH.	WEIGHT OF A CUBIC FOOT IN LBS.	TEMPERATURE, FAH.	WEIGHT OF A CUBIC FOOT IN LBS.
40°	62·408	172°	60·72
42°	62·406	182°	60·55
52°	62·377	192°	60·28
62°	62·321	202°	60·05
72°	62·025	212°	59·82
82°	62·015	230°	59·37
92°	62·004	250°	58·85
102°	61·092	275°	58·17
112°	61·078	300°	57·42
122°	61·063	350°	55·94
132°	61·047	400°	54·34
142°	61·030	450°	52·70
152°	61·011	500°	51·02
162°	60·092	600°	47·64

uoyancy.—When a substance which weighs more per cubic than water is placed in it, it sinks and displaces a quantity water equal to its volume. If a body, lighter per cubic foot n water, is placed in it, it will float, sinking in the water to h a depth that it displaces an amount of water equal in weight ts own weight. Recollecting that liquids transmit and exert ssure in all directions, it will be seen that a floating body is osed to the following forces, tending to raise or lower it.

st. Its weight tending to lower it.

d. The atmospheric pressure tending to lower it.

d. The upward pressure due to the atmosphere pressing down on the exposed surface of the liquid, and hence being transmitted through the water so as to press up just the same amount as the atmosphere presses down on the upper surface of the body.

th. *The upward pressure due to the* water that has been displaced. *nce No. 3 balances No. 2, No. 4* must balance No. 1.

TABLE

SHOWING THE QUANTITY OF WATER PER LINEAL FOOT IN PUM VERTICAL PIPES OF DIFFERENT DIAMETERS.

Diameter of Pump in Inches.	Number of Gallons per Lineal Foot.	Number of Cubic Feet per Lineal Foot.	Diameter of Pump in Inches.	Number of Gallons per Lineal Foot.	Num Cubic per L Fo
2	·136	·0218	8	2·176	·34
2¼	·172	·0276	8¼	2·314	·37
2½	·212	·0340	8½	2·456	·39
2¾	·257	·0412	8¾	2·603	·41
3	·306	·0490	9	2·754	·44
3¼	·359	·0576	9¼	2·909	·46
3½	·416	·0668	9½	3·068	·49
3¾	·478	·0766	9¾	3·232	·51
4	·544	·0872	10	3·400	·54
4¼	·614	·0985	10¼	3·572	·57
4½	·688	·1104	10½	3·748	·60
4¾	·767	·1230	10¾	3·929	·63
5	·850	·1363	11	4·114	·65
5¼	·937	·1503	11¼	4·303	·69
5½	1·028	·1649	11½	4·496	·72
5¾	1·124	·1803	11¾	4·694	·75
6	1·224	·1963	12	4·896	·78
6¼	1·328	·2130	12½	5·312	·85
6½	1·436	·2304	13	5·746	·92
6¾	1·549	·2489	13½	6·196	·99
7	1·666	·2672	14	6·664	1·06
7¼	1·787	·2866	15	7·650	1·22
7½	1·912	·3067	16	8·704	1·39
7¾	2·042	·3275	18	11·016	1·76

One cubic foot of water weighs 62½ lbs., **and contains 7½** gallons.

***One cubic foot of* ice** weighs 57 lbs.

SHOWING THE CAPACITY OF CISTERNS AND TANKS. COMPUTED IN BARRELS OF 31½ GALLONS.

Depth in Feet.	Diameter in Feet.															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5	23·3	33·6	45·7	59.7	75·5	93·2	112·8	134·3	157·6	182·8	209·8	238·7	269·5	302·1	336·6	373·0
6	28·0	40·3	54·8	71·7	90·6	111·9	135·4	161·1	189·1	219·3	251·8	286·5	323·4	362·6	404·0	447·6
7	32·7	47·0	64·0	83·6	105·7	130·6	158·0	188·0	220·6	255·9	293·7	334·2	377·3	423·0	471·3	522·2
8	37·3	53·7	73·1	95·5	120·9	149·2	180·5	214·8	252·1	292·4	335·7	382·0	431·2	483·4	538·6	596·8
9	42·0	60·4	82·2	107·4	136·0	167·9	203·1	241·7	283·7	329·0	377·7	429·7	485·1	543·8	605·9	671·4
10	46·7	67·1	91·4	119·4	151·1	186·5	225·7	268·6	315·2	365·5	419·6	477·4	539·0	604·3	673·3	746·0
11	51·3	73·9	100·5	131·3	166·2	205·1	248·2	295·4	346·7	402·1	461·6	525·2	592·9	664·7	740·6	820·6
12	56·0	80·6	109·7	143·2	181·3	223·8	270·8	322·3	378.2	438·6	503·5	572·9	646·8	725·1	807·9	895·2
13	60·7	87·3	118·8	155·2	196.4	242·4	293·4	349·1	409·7	475·2	545·5	620·7	700·7	785·5	875·2	969·8
14	65·3	94·0	127·9	167·1	211·5	261·1	315·9	376·0	441·3	511·8	587·5	668·4	754·6	846·0	942·6	1044·4
15	70·0	100·7	137·1	179·0	226·6	279·8	338·5	402·8	472·8	548·3	629·4	716·2	808·5	906·4	1009·9	1119·0
16	74·7	107·4	146·2	191·0	241·7	298·4	361·1	429·7	504·3	584·9	671·4	763·9	862·4	966·8	1077·2	1193·6
17	79·3	114·1	155·4	202·9	256·8	317·0	383·6	456·6	535·8	621·4	713·4	811·6	916·3	1027·2	1144·6	1268·2
18	84·0	120·9	164·5	214·8	272·0	335·7	406·2	483·4	567·3	658·0	755·3	859·4	970·2	1087·7	1211·9	1342·8
19	88·7	127·6	173·6	226·8	287·0	354·3	428·8	510·3	598·9	694·5	797·3	907·1	1024·1	1148·1	1279·2	1417·4
20	93·3	134·3	182·8	238·7	302·1	373·0	451·3	537·1	630·4	731·1	839·3	954·9	1078·0	1208·5	1346·5	1492·0

TABLE

SHOWING THE CAPACITY OF CISTERNS IN GALLONS FOR EACH 10-IN
DEPTH.

DIAMETER IN FEET.	GALLONS.	DIAMETER IN FEET.	GALLONS.	DIAMETER IN FEET.	GALLONS.
2·	19·5	6·5	206·8	12	705·
2·5	30·5	7·	239·8	13	827·4
3·	44·6	7·5	275·4	14	959·7
3·5	59·97	8·	313·3	15	1101·6
4·	78·33	8·5	353·7	20	1958·4
4·5	99·14	9·	396·5	25	3059·9
5·	122·4	9·5	461·4	30	4406·4
5·5	148·1	10·	489·6	35	5990·
6·	176·2	11·	592·4	40	7831·

Rule *for finding the quantity of water which any square or r tangular box or tank is capable of containing in cubic feet or U. gallons.*—Multiply the length of the side by the length of the e and by the depth, all in inches. Divide this product by 172 this quotient will be the number of cubic feet of water the tan will contain. To find the number of U. S. gallons, multiply th number of cubic feet by 7·5.

Rule *for finding the cubical contents of a triangular tank.*—Multiply the length of the base of the triangle by half its perpendicul height and by the length of the tank, all in inches. Divide thi product by 1728; this quotient will be the number of cubic feet o water the tank will contain. To find the number of U. S. gallo multiply the number of cubic feet by 7·5.

Rule *for finding the contents of an elliptic or oval tank in cub feet or gallons.*—Multiply the long diameter in inches by th short diameter in inches, this product by ·7854, and this last produ by the height of the tank in inches; then divide by 1728, and th result will be the contents of the tank in cubic feet, which, if mu lied by 7·5, gives the number of U. S. gallons in the tank.

of Water. Head.—If we take a tank containing water, article of water in the bottom layer is subjected to a uniressure equal to the weight of a column of water whose is the distance from the bottom of the tank to the level of er in the vessel. The height of this column of water which es the pressure is always called the "head," and a head of y feet always produces a definite pressure. Thus, if the water in a tank is 12 feet, there is a pressure on each inch of the bottom equal to the weight of a column of water long and 1 square inch in section. This column will have × 1, or 144 cubic inches, or one-twelfth of one cubic foot. ight of one cubic foot at 92° F. and at atmospheric pressure , as given in a previous table, 62 pounds. The weight of umn is therefore one-twelfth of 62 pounds, or $5\frac{1}{6}$ pounds, is is the pressure per square inch due to a head of 12

following table gives the pressures corresponding to variıds at 62° F.

Pressure in pounds.	Head in feet.	Pressure in pounds.
.4328	10	4.328
.9656	20	9 656
1.2984	30	12.984
1.7312	40	17.312
2.1640	50	21.640
2.5968	60	25.968
3.0296	70	30.296
3.4624	80	34.624
3.8952	90	38.952

he pressure in pounds per square inch is proportional to ıd, it follows that to get the pressure corresponding to 100 multiply the pressure at 10 feet head by 10. The presse to 57 feet is equal to the pressure due to 50 plus the e due to 7 feet.

mple—**What** *will be the pressure* due to a head of 1287

Pressure due to 1000 feet = 100 times that of 10 feet = 432.8
" " 200 " = 10 " " 20 " = 96.56
" " 80 " = ... 34.624
" " 7 " = ... 3.029
" " 1287 " = ... 567.013

To change from pounds pressure to the equivalent head
following table calculated for 62° F.

Pressure in pounds.	Head in feet.	Pressure in pounds.	
1	2.31	10	
2	4.62	20	
3	6.93	30	
4	9.24	40	
5	11.55	50	
6	13.86	60	
7	16.17	70	
8	18.48	80	
9	20.79	90	

Example.—What head of water will produce a pressure
pounds per square inch?

100 pounds will be produced by a head of 23.1 × 10 or 231.0 f
20 " " " " " 46.2
6 " " " " " 13.86
126 " " " " " 291.06

Flow from an Orifice in Bottom of Tank.—Here the p
coming out are under a head equal to the height of wate
tank. It is supposed that this level is kept constant. The v
at which they fall is the same as a drop would acquire if
held at the upper surface of the water and let fall to the
From the first chapter of this book this velocity equals the
root of 2 × 32.2 × the head. This is the velocity if there v
friction at the mouth of the orifice, but in practice the v
will be actually only 62 per cent. of the value above given
following rule is the most convenient: To obtain the veloci
given head in feet multiply the square root of the head b
the result will be the velocity in feet per second.

Example.—A tank has a hole in the bottom and water is mped into it so as to keep always five feet depth. At what locity will the water come out?

From the table of square roots, the square root of 5 is 2.236; mul- plying by 5 we obtain 11.16 feet per second as the velocity of flow.

The quantity of water in cubic feet per minute flowing out of e above tank is equal to the velocity multiplied by the area. If hole had a diameter of 4 inches, the area will be 12.5664 are inches, or .872 square foot. The velocity is 11.16 × 60, or .6 feet per minute, and the number of cubic feet of water ping per minute is .872 × 669.6 = 583.89 cubic feet per minute.

Flow from Orifice in the Side of Tank.—In this case the par- es at the upper part of the hole have a less head and less velocity n those at the lower part. The following table, taken from the logue of the Pelton Water Wheel Company, gives the quan- y in cubic feet of water discharged per minute, through an ori- e one inch square, under any head of water from 3 to 72 inches:

FOR TANK MEASUREMENT.

ADS IN CHES.	Cubic Feet Disch'd per minute.	HEADS IN INCHES.	Cubic feet Discharged per minute.	HEADS IN INCHES.	Cubic feet Disch'd per minute	HEADS IN INCHES.	Cubic feet Discharged per minute.	HEADS IN INCHES.	Cubic feet Disch'd per minute.
3	1.12	17	2.51	31	3.36	45	4.05	59	4.63
4	1.27	18	2.58	32	3.41	46	4.09	60	4.65
5	1.40	19	2.64	33	3.47	47	4.12	61	4.72
6	1.52	20	2 71	34	3.52	48	4.18	62	4.74
7	1.64	21	2.78	35	3.57	49	4.21	63	4.78
8	1.75	22	2.84	36	3.62	50	4.27	64	4.81
9	1.84	23	2.90	37	3.67	51	4.30	65	4.85
10	1.94	24	2.97	38	3.72	52	4 34	66	4.89
11	2.03	25	3.03	39	3.77	53	4.39	67	4.92
[illegible]	2.12	26	3.08	40	3.81	54	4.42	68	4.97
	2.20	27	3.14	41	3.86	55	4.46	69	5.00
	2.28	28	3.20	42	3.91	56	4.52	70	5.03
15	2.36	29	3.25	43	3.95	57	4.55	71	5.07
16	2.43	30	3.31	44	4.00	58	4.58	72	5.09

Example Showing the Application of the Preceding Tabl Suppose the opening to be 36 inches long and 2 inches high, the head of water above the opening 25 inches. Multiply length 36 by 2, the height of the opening, and it gives 72. ferring to the preceding table, opposite 25 inch head will be fo 3.03. This multiplied by 72 gives 218.16, the number of c feet of water passing through the opening per minute.

Flow of Water through Pipes.—The values of velocity quantity per second will differ somewhat according as the pip old or new, owing to the different amounts of friction of the w against the walls of the pipe. The friction produces a los pressure or head, and the amount of head lost is proportiona the length of pipe. The following tables, showing the loss of h by friction in each 100 feet in length of different diameters of when discharging the following quantities of water per minute, taken from the Pelton Water Wheel Company's catalogue:

LOSS OF HEAD IN PIPE BY FRICTION.

Inside Diameter of Pipe in Inches.

	1		2		3		4		5		6	
Velo in ft. per sec.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cu fe p m
2.0	2.37	.65	1.185	2.62	.791	5.89	.593	10.4	.474	16.3	.395	[illegible]
2.2	2.80	.73	1.404	2.88	.936	6.48	.702	11.5	.561	18.	.468	[illegible]
2.4	3.27	.79	1.639	3.14	1.093	7.07	.819	12.5	.650	19.6	.547	[illegible]
2.6	3.78	.86	1.891	3.40	1.26	7.65	.945	13.6	.757	21.3	.631	[illegible]
2.8	4.32	.92	2.16	3.66	1.44	8.24	1.08	14.6	.864	22.9	.720	[illegible]
3.0	4.89	.99	2.44	3.92	1.62	8.83	1.22	15.7	.978	24.5	.815	[illegible]
3.2	5.47	1.06	2.73	4.18	1.82	9.42	1.37	16.7	1.098	26.2	.915	[illegible]
3.4	6.09	1.12	3.05	4.45	2.04	10.00	1.52	17.8	1.22	27.8	1.021	[illegible]
3.6	6.76	1.19	3.38	4.71	2.26	10.60	1.69	18.8	1.35	29.4	1.131	[illegible]
3.8	7.48	1.26	3.74	4.97	2.49	11.20	1.87	19.9	1.49	31.	1.25	[illegible]
4.0	8.20	1.32	4.10	5.23	2.73	11.80	2.05	20.9	1.64	32.7	1.37	[illegible]
4.2	8.97	1.39	4.49	5.49	2.98	12.30	2.24	22.0	1.79	34.8	1.49	[illegible]
4.4	9.77	1.45	4.89	5.76	3.25	12.90	2.43	23.0	1.95	36.0	1.62	[illegible]
4.6	10.60	1.52	5.30	6.02	3.53	13.50	2.64	24.0	2.11	37.6	1.76	[illegible]
4.8	11.45	1.58	5.72	6.28	3.81	14.10	2.85	25.1	2.27	39.2	1.90	[illegible]
5.0	12.33	1.65	6.17	6.54	4.11	14.70	3.08	26.2	2.46	40.9	2.05	[illegible]
5.2	13.24	1.72	6.62	6.80	4.41	15.30	3.31	27.2	2.65	42.5	2.21	[illegible]
5.4	14.20	1.78	7.10	7.06	4.73	15.90	3.55	28.2	2.84	44.2	2.37	[illegible]
5.6	15.16	1.85	7.58	7.32	5.06	16.50	3.79	29.3	3.03	45.8	2.53	[illegible]
5.8	*16.17*	*1.91*	*8.09*	7.58	5.40	17.10	4.04	30.3	3.24	47.4	2.70	[illegible]
6.0	*17.23*	*1.98*	*8.61*	7.85	5.74	17.70	4.31	31.4	3.45	49.1	2.87	[illegible]
7.0	*22.89*	*2.31*	*11.45*	9.16	7.62	20.6	5.72	36.6	4.57	57.2	3.81	[illegible]

Inside Diameter of Pipe in Inches.

7		8		9		10		11		12	
of d t.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.
38	32.0	.296	41.9	.264	53.	.237	65.4	.216	79.2	.198	94.2
01	35.3	.351	46.1	.312	58.3	.281	72.	.255	87.1	.234	103.
68	38.5	.410	50.2	.365	63.6	.327	78.5	.297	95.0	.273	113.
40	41.7	.473	54.4	.420	68.9	.378	85.1	.344	103.	.315	122.
17	44.9	.540	58.6	.480	74.2	.432	91.6	.392	111.	.360	132.
98	48.1	.611	62.8	.544	79.5	.488	98.2	.444	119.	.407	141.
85	51.3	.686	67.	.609	84.8	.549	105.	.499	127.	.457	151.
75	54.5	.765	71.2	.680	90.1	.612	111.	.557	134.	.510	160.
69	57.7	.848	75.4	.755	95.4	.679	118.	.617	142.	.566	169.
70	60.9	.936	79.6	.831	101.	.749	124.	.680	150	.624	179.
75	64.1	1.027	83.7	.913	106.	.822	131.	.747	158.	.685	188.
8	67.3	1.122	87.9	.998	111.	.897	137.	.816	166.	.749	198.
9	70.5	1.22	92.1	1.086	116.	.977	144.	.888	174.	.815	207.
1	73.7	1.32	96.3	1.177	122.	1.059	150.	.963	182.	.883	217
3	76.9	1.43	100.0	1.27	127.	1.145	157.	1.040	190.	.954	226
6	80.2	1.54	105.	1.37	132.	1.23	163.	1.122	198.	1.028	235.
9	83.3	1.65	109.	1.47	138.	1.32	170.	1.20	206.	1.104	246
3	86.6	1.77	113.	1.57	143.	1.41	177.	1.28	214.	1.183	254.
7	89.8	1.89	117.	1.68	148.	1.51	183.	1.37	222.	1.26	264.
1	93.0	2.01	121.	1.80	154.	1.61	190.	1.46	229.	1 34	273.
6	96.2	2.15	125.	1.92	159.	1.71	196.	1.56	237.	1.43	283.
6	112.0	2.85	146.	2.52	185.	2.28	229.	2.07	277.	1.91	330.

mple.—Have 200 feet head and 600 feet of 11 inch pipe, ıg 119 cubic feet of water per minute. To find effective In right hand column under 11 inch pipe, find 119 cubic ›posite this will be found the coefficient of friction for this t of water, which is .444. Multiply this by the number of ›d feet of pipe, which is 6, and we will have 2.66 feet, which oss of head. Therefore, the effective head is 200 – 2.66 =

er Power—*Rule for finding the horse-power of waterfalls.*—ly the area of the cross-section of the waterfall in feet by its y in feet per minute; this product will give the number of feet flowing through per minute. Multiply this by 62½ ı, the number of pounds in a cubic foot of water. Multiply ›t product by the fall in feet, and divide by 33,000. The ıt will be the horse-power of the waterfall.

mple.—Given a stream or flume 10 feet; depth, 4 feet; area ›s-section, 40 feet; velocity in feet per minute, 150. Then 0 = 6,000 cubic *feet of water* per minute; 6,000 × 62½ = *0 pounds of water per minute.* 10 × 375,000 = 3,750,000 foot-pounds of the waterfall; $3{,}750{,}000 + 33{,}000 - 113\frac{7}{11}$ h power of the waterfall.

The above rule gives the theoretical horse-power, but power developed by a wheel would be less than this. The ber of horse-power obtained would be from 70 to 85 per cen the above value, depending on the size and type of wheel use

The following table does away with the last part of the cal tion and gives the horse-power for each cubic foot of water u different heads, with a wheel efficiency of 85 per cent., so after obtaining the number of cubic feet and the head it is necessary to look up the number corresponding to the head multiply it by the number of cubic feet per minute.

Heads in Feet.	Horse Power	Heads in Feet.	Horse Power.
1	.0016098	320	.515136
20	.032196	330	.531234
30	.048294	340	.547332
40	.064392	350	.563430
50	.080490	360	.579528
60	.096588	370	.595626
70	.112686	380	.611724
80	.128784	390	.627822
90	.144892	400	.643920
100	.160980	410	.660018
110	.177078	420	.676116
120	.193176	430	.692214
130	.209274	440	.708312
140	.225372	450	.724410
150	.241470	460	.740508
160	.257568	470	.756606
170	.273666	480	.772704
180	.289764	490	.788802
190	.305862	500	.804900
200	.321960	520	.837096
210	.338058	540	.869292
220	.354156	560	.901488
230	.370254	580	.933684
240	.386352	600	.965880
250	.402450	650	1.046370
260	.418548	700	1.126860
270	.434646	750	1.207350
280	.450744	800	1.287840
290	.466842	900	1.448820

What a Horse-Power will raise per Minute.		2 H. P. will raise per Minute.		3 H. P. will raise per Minute.		4 H. P. will raise per Minute.		5 H. P. will raise per Minute.		6 H. P. will raise per Minute.		7 H. P. will raise per Minute.		8 H. P. will raise per Minute.	
Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.
2,500	1	5,000	1	7,500	1	10,000	1	12,500	1	15,000	1	17,500	1	20,000	1
1,250	2	2,500	2	3,750	2	5,000	2	6,250	2	7,500	2	8,750	2	10,000	2
833	3	1,666	3	2,500	3	3,333	3	4,166	3	5,000	3	5,833	3	6,666	3
625	4	1,250	4	1,875	4	2,500	4	3,125	4	3,750	4	4,375	4	5,000	4
500	5	1,000	5	1,500	5	2,000	5	2,500	5	3,000	5	3,500	5	4,000	5
416	6	833	6	1,250	6	1,666	6	2,083	6	2,500	6	2,916	6	3,333	6
357	7	714	7	1,070	7	1,428	7	1,785	7	2,142	7	2,500	7	2,857	7
312	8	625	8	937	8	1,250	8	1,562	8	1,875	8	2,187	8	2,500	8
277	9	555	9	833	9	1,111	9	1,388	9	1,666	9	1,944	9	2,222	9
250	10	500	10	750	10	1,000	10	1,250	10	1,500	10	1,750	10	2,000	10
125	20	250	20	375	20	500	20	625	20	750	20	875	20	1,000	20
83	30	166	30	250	30	333	30	416	30	500	30	583	30	666	30
62	40	125	40	187	40	250	40	312	40	375	40	437	40	500	40
50	50	100	50	150	50	200	50	250	50	300	50	350	50	400	50
41	60	83	60	125	60	166	60	208	60	250	60	291	60	333	60
35	70	71	70	107	70	142	70	178	70	214	70	250	70	285	70
31	80	62	80	93	80	125	80	156	80	187	80	218	80	250	80
27	90	55	90	83	90	111	90	138	90	166	90	194	90	222	90
25	100	50	100	75	100	100	100	125	100	150	100	175	100	200	100

CHAPTER VIII.

STEAM.

Steam is an elastic fluid resulting from the combination of with water, and, when the steam is not in contact with the wa from which it is formed, it follows the same general law as other gases. This law is as follows: All gases expand by heat part of their volume for every degree Fah., while their el pressure remains unaltered, and so long as the temperature gas remains unaltered, its elastic pressure will vary inversely the volume.

The temperature of the steam is always equal to that of water from which it is formed, and the elastic force of st formed is equal to the pressure under which it is formed. elastic force of steam, barometer at 30°, at 212° Fah., is one mosphere, or 14·7 lbs. per sq. inch; while at 250° Fah. its el force is two atmospheres, or 29·4 lbs. per sq. inch. This inclu the pressure of the atmosphere.

If the mercury be in a vacuum, the pressure of steam due temperature of 212° Fah. will equal 30 inches, and for a pres due to a temperature of 250° Fah. it will equal 60 inches; if the mercury be exposed to the atmosphere, the pressure du 250° Fah. will only equal 30 inches of mercury, and for Fah. there is no indication by a mercury gauge, as steam at just balances the atmosphere.

Saturated steam is the vapor formed from water at a gi temperature and pressure, and either remaining in contact with water, or, if not in contact, withdrawn from any further heati *At a given temperature* it always exerts a certain pressure.

***Superheated* steam** is produced by taking saturated steam ng it to a higher temperature than that corresponding to the ure at which it was generated.

dinary steam coming from the boiler has suspended in it te particles of *water*, and the percentage which the weight is moisture bears to the weight of the steam varies with the ure as well as the individual boiler, but runs approximately llows:

e pressure.............	60	70	80	90	100	110	120	130	140	150
ent. moisture.........	3.2	3.5	3.8	4.1	4.4	4.6	4.8	5.1	5.3	5.5

ry saturated steam is steam only, without any such water par- in mechanical suspension.

he latent heat of steam is heat that is neither sensible to the h, nor can it be indicated by the thermometer. The existence is latent heat in water, while in the form of steam, may be ed by the following illustration: If 5½ pounds of water, at F., are placed in a vessel communicating with another, in h water is kept at 212° F., and kept there till the former es a temperature of 212° F., and then weighed, it will be d to weigh 6½ pounds, showing that 1 pound of water has added to the 5½ pounds in the form of steam. This pound ater, received in the form of steam had, when in that form, a erature of 212° F. It still possesses the same temperature of F., showing that it has parted with 5½ times the number of es of temperature between 32° and 212°, which is 180, and 180 = 990°. This heat was combined with the steam, but not sensible to the thermometer is called latent; in this connec- 5½ is taken as a convenient number; 5.37 is more accurate.

we observe the time that a certain amount of heat takes to water from 32° to 212°, no matter what the time may be, it take 5½ times as long for the same heat to evaporate the amount of water. It follows, that to evaporate water under ressure of the atmosphere requires 5½ times as much heat as d be necessary to *raise the same* amount from 32° F. to F.

TABLE

SHOWING THE STEAM PRESSURE IN POUNDS PER GAUGE; THE AB
PRESSURE IN POUNDS AND INCHES OF MERCURY; THE TEMPER
THE TOTAL HEAT IN STEAM PER POUND; THE LATENT HEAT PER
THE HEAT OF THE WATER; THE RELATIVE VOLUME, AND WEI
STEAM PER CUBIC FOOT, FOR VARIOUS PRESSURES.

Pressure per Gauge.	Total lbs.	Inches of Mercury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Water per lb.	Relative Volume.
36·304	51	103·84	282·10	1198·98	915·74	284·24	498·89
37·304	52	105·87	283·32	1200·35	914·86	285·50	489·85
38·304	53	107·91	284·53	1200·72	913·99	286·73	481·15
39·304	54	109·94	285·72	1201·08	913·13	287·95	472·77
40·304	55	111·98	286·89	1201·44	912·29	289·15	464·69
41·304	56	114·02	288·05	1201·80	911·46	290·34	456·90
42·304	57	116·05	289·11	1202·14	910·64	291·50	449·38
43 304	58	118·09	290·32	1202·49	909·83	292·65	442·12
44·304	59	120·12	291·42	1202·82	909·03	293·79	435·10
45·304	60	122·16	292·52	1203·16	908·25	294·91	428·32
46·304	61	124·19	293·60	1203·49	907·47	296·02	421·75
47·304	62	126·23	294·66	1203·81	906·70	297·11	415·40
48·304	63	128·27	295·71	1204·13	905·95	298·18	409·25
49·304	64	130·30	296·75	1204·45	905·20	299·25	403·29
50·304	65	132·34	297·78	1204·76	904·46	300·30	397·51
51·304	66	134·37	298·79	1205·07	903·73	301·34	391·90
52·304	67	136·41	299·79	1205·38	903·01	302·37	386·47
53·304	68	138·45	300·77	1205·68	902·30	303·38	381·18
54·304	69	140·48	301·75	1205·97	901·60	304·37	376·06
55·304	70	142·52	302·72	1206·27	900 90	305·37	371·07
56·304	71	144·55	303·67	1206·56	900·21	306·35	366·24
57 304	72	146·59	304·62	1206·85	899·53	307·32	361·53
58·304	73	148·63	305·55	1207·13	898·85	308·28	356·95
59·304	74	150·66	306·47	1207·42	898·19	309·23	352·49
60·304	75	152·70	307·39	1207·69	897·53	310·16	348·15
61·304	76	154·73	308·29	1207·97	896·88	311·09	343·93
62·304	77	156·77	309·18	1208·24	896·23	312·01	339·81
63·304	78	158·81	310·07	1208·51	895·59	312·92	335·81
64·304	79	160·84	310·94	1208·78	894·95	313·82	331·89
65·304	80	162·88	311·81	1209·04	894·33	314·71	328·08
66·304	81	164·91	312·67	1209·30	893·71	315·59	324·37
67·304	82	166·95	313·52	1209·56	893·09	316·47	320·74
68·304	83	168·99	314·36	1209·82	892·49	317·33	317·20
69·304	84	171·02	315·19	1210·07	891·88	318·19	313·74
70·304	85	173·06	316·02	1210·33	891·29	319·04	310·36
71·304	86	175·09	316·84	1210·58	890·69	319·89	307·07
72·304	87	177·13	317·65	1210·83	890 11	320·72	303·85
73·304	88	179·17	318·45	1211·07	889·52	321·54	300·70
74·304	89	181·20	319·25	1211·31	888·95	322·36	297·62
75·304	90	185·24	320·04	1211·55	888·38	323·17	294·61
76·304	91	185·27	320·82	1211·79	887·81	323·98	291·66
77·304	92	187·31	321·58	1212·03	887·25	324·78	288·78
78·304	93	189·35	322·36	1212·26	886·69	325·57	285·96
79·304	94	191·38	323·13	1212·49	886·13	326·36	283·21
80·304	95	193·42	323·88	1212·72	885·59	327·13	280·50
81·304	96	195·45	324·63	1212·95	885·04	327·91	277·86
82·304	97	197·49	325·38	1213·18	884·50	328·68	275·27
83·304	98	199·53	326·11	1213·40	883·97	329·43	272·78
84·304	99	201·56	326·84	1213·63	883 44	330·19	270·24
85 304	100	203·60	327·57	1213·85	882·91	330·94	267·80

TABLE

THE STEAM PRESSURE IN POUNDS PER GAUGE; THE ABSOLUTE
RE IN POUNDS AND INCHES OF MERCURY; THE TEMPERATURE;
TAL HEAT IN STEAM PER POUND; THE LATENT HEAT PER POUND;
EAT OF THE WATER; THE RELATIVE VOLUME AND WEIGHT OF
PER CUBIC FOOT, FOR VARIOUS PRESSURES.

Total lbs.	Inches of Mercury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Water per lb.	Relative Volume.	Weight per Cub. Ft.
101	205·64	328·29	1214·07	882·39	331·68	265·81	·23505
102	207·67	329·00	1214·28	881·87	332·41	263·07	·23715
103	209·71	329·71	1214·50	881·35	333·15	260·77	·23924
104	211·74	330·42	1214·71	880·85	333·86	258·52	·24132
105	213·78	331·11	1214·93	880·34	334·59	256·31	·24340
106	215·82	331·80	1215·14	879·84	335·30	254·14	·24548
107	217·85	332·49	1215·35	879·34	336·01	252·01	·24756
108	219·89	333·17	1215·55	878·84	336·71	249·92	·24963
109	221·92	333·85	1215·76	878·35	337·41	247·87	·25169
110	223·96	334·52	1215·97	877·86	338·11	245·86	·25375
111	225·99	335·19	1216·17	877·38	338·79	243·88	·25581
112	228·03	335·85	1216·38	876·90	339·48	241·94	·25786
113	230·07	336·51	1216·58	876 42	340·16	240·03	·25991
114	232·10	337·16	1216·77	875·94	340·83	238·15	·26204
115	234·14	337·81	1216·97	875·47	341·50	236·31	·26400
116	236·17	338·46	1217·17	875·00	342·17	234·50	·26611
117	238·21	339·10	1217·36	874·54	342·83	232·70	·26816
118	240·25	339·73	1217·56	874·07	343·49	231·00	·27020
119	242·28	340·37	1217·75	873·61	344·14	229·30	·27224
120	244·32	340·99	1217·94	873·15	344·79	227·56	·27421
121	246·35	341·62	1218·13	872·70	345·43	226·00	·27628
122	248·39	342·24	1218·32	872·25	346·07	224·40	·27828
123	250·43	342·85	1218·51	871·80	346·71	222·80	·28027
124	252·46	343·46	1218·69	871·35	347·34	221·20	·28227
125	254·50	344·07	1218·88	870·91	347·97	219·50	·28422
126	256·54	344·68	1219·07	870·47	348·60	218·20	·28625
127	258·57	345·28	1219·25	870·03	349·22	216·70	·28824
128	260·61	345·87	1219·43	869·60	349·83	215·20	·29023
129	262 64	346·46	1219·61	869·16	350·45	213·70	·29222
130	264·68	347·06	1219·79	868·74	351·06	212·07	·29419
131	266·72	347·64	1219·97	868·31	351·66	210·90	·29618
132	268·75	348·23	1220·15	867·88	352·27	209·50	·29816
133	270·79	348·80	1220·32	867·46	352·86	208·10	·30013
134	272·82	349·38	1220·50	867·04	353·46	206·70	·30209
135	274·86	349·95	1220·67	866·62	354·05	205·18	·30406
136	276·89	350·52	1220·85	866·21	354·64	204·10	·30601
137	278·93	351·09	1221·02	865·79	355·23	202·80	·30796
138	280·96	351·75	1221·19	865·38	355·81	201·50	·30990
139	283·00	352·21	1221·36	864·97	356·39	200·20	·31186
140	285·04	352·76	1221·53	864·56	356·97	198·78	·31385
141	287·07	353·32	1221·70	864·16	357·54	197·80	·31586
142	289·11	353·87	1221·87	863·76	358·11	196·60	·31788
143	291·15	354·42	1222·04	863·36	358·67	195·40	·31990
144	293·18	354·96	1222·20	862·96	359·24	194·20	·32190
145	295·22	355·50	1222·37	862·57	359·80	192·83	·32354
146	297·25	356·04	1222·53	862·17	360·36	191·90	·32592
147	299·29	356·57	1222·69	861·78	360·91	190·80	·32794
148	301·33	357·10	1222·85	861·39	361·46	189·70	·32995
149	303·36	357·63	1223·02	861·01	362·01	188·60	·33196
150	305·40	358·16	1223·18	860·62	362·56	187·26	·33315

The values given by different authors for the relative volu and weight of steam differ somewhat. Those in the tables sufficiently accurate.

Condensation.—When steam condenses into water the lat heat of vaporization is given up to surrounding air and obje and afterward the heat in the liquid is likewise given out.

Use of the Tables.—The following examples will serve illustrations:

What is the gauge pressure corresponding to the pressure the atmosphere? *Ans.* Zero pounds at sea level.

What is the absolute pressure of the atmosphere or press above the vacuum? *Ans.* 14.7 pounds.

What height of mercury column corresponds to 36 pounds ab lute or 21.3 pounds gauge? *Ans.* 73.296 inches.

What is the temperature of saturated steam at this pressur *Ans.* 260.83° F.

What will one cubic foot of steam weigh at this temperatur *Ans.* .08987 pound.

How much more heat will it take to raise one pound of wat from 32° to 183° than from 32° to 153°?

Ans. Heat in water at 183° = 183 heat units.
" " " 153° = 153.4 " nearly.

Difference equals 29.6 heat units. To heat 10 pounds wou require 296 heat units more.

How much more coal would it require to raise one pound water to steam at 100 pounds absolute than to steam at 15 poun absolute?

Ans. Total heat 1 pound steam at 100 pounds = 1213.85
" 1 " " 15 " 1178.91
" units to raise from 15 to 100 lbs. 34.94

34.94 is nearly 3 per cent. of 1178.91; therefore it will take per cent. more coal.

The tables show why the exhaust steam from an engine at, sa *5 pounds pressure* is nearly as good for heating purposes as li *steam from the* boiler at 100 pounds, 1 pound at 5 pounds pre re having a total heat in it of 1180 units nearly, while at 100 ounds gauge pressure the total heat is only 1216 units.

Flow of Steam from an Orifice.—When the pressure of the eam is more than 1.7 times atmospheric pressure the following ble, taken from D. K. Clark, applies:

OUTFLOW OF STEAM INTO THE ATMOSPHERE.

Absolute initial pressure in lbs. per sq. in.	External pressure in lbs. per sq. in.	Ratio of expansion in nozzle.	Velocity of outflow at constant density.	Actual velocity of outflow, expanded.	Discharge per sq. in. of orifice per min.
Lbs.	Lbs.	Ratio.	Ft. per sec.	Ft. per sec.	Lbs.
25.37	14.7	1.624	863	1401	22.81
30	14.7	1.624	867	1408	26.84
40	14.7	1.624	874	1419	35.18
45	14.7	1.624	877	1424	39.78
50	14.7	1.624	880	1429	44.06
60	14.7	1.624	885	1437	52.59
70	14.7	1.624	889	1444	61.07
75	14.7	1.624	891	1447	65.30
90	14.7	1.624	895	1454	77.94
100	14.7	1.624	898	1459	86.34
115	14.7	1.624	902	1466	98.76
135	14.7	1.624	906	1472	115.61
155	14.7	1.624	910	1478	132.21
165	14.7	1.624	912	1481	140.46
215	14.7	1.624	919	1493	181.58

Flow of Steam in Pipes.—Mr. George H. Babcock, in "Steam," ives the following method and tables by which can be determined either the number of cubic feet per minute which can be assed through different sized pipes for a given loss in pressure, r what will be the loss of pressure owing to friction in different ized pipes for different rates of flow.

Flow of Steam through Pipes.—The approximate weight of ny fluid which will flow one minute through any given pipe with given head or pressure may be found by the following formula:

$$W = 87\sqrt{\frac{D\,(p_1-p_2)\,d^5}{L\left(1+\frac{3.6}{d}\right)}}$$

in which W = weight in pounds avoirdupois, d = diameter i inches, D = density of weight per cubic foot; p_1 the initial pre ure, p_2 pressure at end of pipe, and L = the length in feet.

The following table gives, approximately, the weight of ste per minute which will flow from various initial pressures, with o pound loss of pressure through straight, smooth pipes, each havi a length of 240 times its own diameter.

For sizes of pipe below 6-inch, the flow is calculated from t *actual* areas of "standard" pipe of such nominal diameters.

For horse-power, multiply the figures in the table by 2. F any other loss of pressure, multiply by the square root of t given loss. For any length of pipe, *divide 240 by the given leng expressed in diameters, and multiply the figures in the table by t square root of this quotient,* which will give the flow for 1 pou loss of pressure. Conversely, dividing the given length by 24 will give the loss of pressure for the flow given in the table.

TABLE OF FLOW OF STEAM THROUGH PIPES.

Initial pressure by gauge. lbs. per sq. in.	Diameter of Pipe in inches. Length of each = 240 diameters.									
	¾	1	1½	2	2½	3	4	5	6	8
	Weight of Steam per minute in pounds, with one Pound loss of pressure.									
1	1.16	2.07	5.7	10.27	15.45	25.38	46.85	77.3	115.9	211.4
10	1.44	2.57	7.1	12.72	19.15	31.45	58.05	95.8	143.6	262.0
20	1.70	3.02	8.3	14.94	22.49	36.94	68.20	112.6	168.7	307.8
30	1.91	3.40	9.4	16.84	25.35	41.63	76.84	126.9	190.1	346.8
40	2.10	3.74	10.3	18.51	27.87	45.77	84.49	139.5	209.0	381.3
50	2.27	4.04	11.2	20.01	30.13	49.48	91.34	150.8	226.0	412.2
60	2.43	4.32	11.9	21.38	32.19	52.87	97.60	161.1	241.5	440.5
70	2.57	4.58	12.6	22.65	34.10	56.00	103.37	170.7	255.8	466.5
80	2.71	4.82	13.3	23.82	35.87	58.91	108.74	179.5	269.0	490.7
90	2.83	5.04	13.9	24.92	37.52	61.62	113.74	187.8	281.4	513.3
100	2.95	5.25	14.5	25.96	39.07	64.18	118.47	195.6	293.1	534.6
120	3.16	5.63	15.5	27.85	41.93	68.87	127.12	209.9	314.5	573.7
150	3.45	6.14	17.0	30.37	45.72	75.09	138.61	228.8	343.0	625.5

The loss of head due to getting up the velocity, to the frictio of the steam entering the pipe, and passing elbows and valves will reduce the flow given in the tables. The resistance at th *opening,* and *that* at a globe valve, are each about the same a *that for a length* of pipe equal to 114 diameters divided by a nu

· represented by 1 + (3.6 ÷ diameter). For the sizes of pipes en in the table, these corresponding lengths are:

1	1½	2	2½	3	4	5	6	8	10	12	15	18
25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to ⅔ that of a globe valve. iese equivalents—for opening, for elbows, and for valves—ust be added in each instance to the actual length of pipe. hus a 4-inch pipe, 120 diameters (40 feet) long, with a globe lve and three elbows, would be equivalent to 120 + 60 + (3 × 40) ·360 diameters long; and 360 ÷ 240 = 1½. It would therefore ave 1½ pounds loss of pressure at the flow given in the table, or eliver $(1 + \sqrt{1\frac{1}{2}} = .816)$, 81.6 per cent. of the steam with the me (1 pound) loss of pressure.

Equivalent Sizes of Pipe.

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1,096
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32	
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99
18	20,327	7,810	2,691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63
20	26,676	10,249	3,532	1,102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07
24	42,624	16,376	5,644	1,761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5
48	249,351	95,818	33,020	10,301	4,554	2,434	1,465	663	363	223	146	102	75.0	56.8
Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10

Steam Pipes—Sizes.—For engines the average practice is to have steam pass through the supply pipes at a velocity mo than 6000 feet per minute, and sizes run about as follows:

Diameter of pipe............	2''	3''	4''	5''	6''	7''	8
Horse-power of engine.....	25	50	100	150	225	300	40

To calculate the mains the preceding table from "Steam" ca be used. The upper part of the table above the diagonal wh space refers to standard sizes or nominal inside diameters. T lower part is for actual inside diameters. The table tells ho many pipes of one size are equivalent to one pipe of another size

Example of Use of Table.—Suppose we have 3 engines, on of 50 horse-power and two of 25 horse-power. What size ma steam pipe shall we use? If the main were exceedingly long, w might have to calculate it by the preceding article on *Flow* *Steam;* but for mains of ordinary length proceed as follows:

Assume that the 50-horse-power engine has a 3″ pipe and th 25 horse-power a 2″ pipe. From the table one 3″ pipe equa

SHOWING RADIATION DUE TO BARE AND COVERED PIPES, AND SAVING DUE TO COVERINGS.

KINDS OF COVERING.	B. T. U. Transmitted per Hour per Square Foot Pipe per Degree Difference in Temperature.	Lbs. Steam Condensed per Hour per Square Foot Pipe per Degree Difference in Temperature.	Lbs. Steam Saved per 100 Square Feet Pipe per Year.	Saving in Dollars per 100 Square Feet Pipe per Year.
Bare Pipe..........	2.7059	.003107	....	———
Magnesia..........	.3838	.000432	635,801	$110.82
Rock Wool..........	.2556	.000285	670,666	116.90
Mineral Wool	.2846	.000311	662,957	115.55
Fire Felt	.5023	.000591	603,389	105.17
Manville Sectional	.3496	.000409	645,174	112.45
Manville Sectional and Hair Felt	.2119	.000243	682,930	119.03
Manville Wool Cement..	.3448	.000410	646,488	112.68
Champion Mineral Wool,	.3166	.000364	654,197	114.03
Hair Felt	.4220	.000472	625,376	109.00
Riley Cement..........	.9531	.001089	479,960	88.66
Fossil Meal	.8787	.001010	500,284	87.20

2-inch pipes. The main needs to be equal to seven 2″ pipes. king again in the table opposite 2 we find that a 4″ pipe is al to 6.47 2-inch pipes, and the size to use will be the next larger, or 4½″.

imensions of steam pipe will be found in the chapter on terials. See index.

oss by condensation in steam-pipes is very considerable ess coverings are employed. The preceding table, taken from lios, shows the gain in using pipe coverings, assuming the cost coal at $2.50 per ton, the cost of firing 12 cents per hour, and evaporation of 7 pounds of water per pound of coal burned.

QUESTIONS.

What is the difference between heat and temperature?

How would you measure the number of heat units in a body?

What are the name and general principle of the instrument ed for measuring temperature?

What is the difference between the Fahrenheit and the centi-rade scales?

What is the difference between melting point and boiling point?

What is the absolute zero of temperature?

What is the mechanical equivalent of heat?

How many pounds of water will be raised 1 degree Fahren-eit by expending 1 horse-power on the water for the period of hour?

What is latent heat?

What is the relation between total heat, latent heat of vaporiza-on, and the heat of the liquid?

In what three ways is heat transferred?

Give the meaning of the term fuel.

Give the component parts of various kinds of fuel.

Give the comparative values of various kinds of wood for the rpose of *fuel as compared with* coal.

Give the definitions of the terms fire and smoke.

Define the term specific heat.

Give the specific heat of different substances.

Give the conductive properties of different substances.

Define the terms combustion and spontaneous combustion.

What are the advantages of liquid fuels, as petroleum?

Why is it not used more widely?

What is the pressure of the atmosphere at sea-level?

Give the estimated height of the atmosphere.

Give the component parts of atmospheric air.

State the difference in weight between air, water, and mercu

Does the pressure of the atmosphere differ in different loc ties?

Is the pressure of the atmosphere constant in the same localit

What is a perfect gas? Give some examples.

State the law of Boyle.

What is the distinction between a gas and a vapor?

To which class does steam belong?

Of what is water composed and in what ratio by weight?

Which has the greater specific gravity, salt or fresh water?

In what three physical states does water exist?

Describe the effect of heat on water.

Which is heavier, 1 cubic foot of water at 90° F. or 1 cul foot at 40° F.?

What is meant by the "head" of a body of water?

How many pounds pressure will be produced by a head of foot?

To what are the temperature and the elastic force of steam equ

What is the difference in the pressure of steam when the m cury is in a vacuum, or when exposed to the atmosphere?

What is steam?

Is dry, saturated steam visible?

What law does the expansive property of steam follow?

What is superheated steam?

" affect the vacuum?

What is saturated steam?

What is supersaturated steam?

What is the total heat of steam at 212° F.?

How is the latent heat of steam found?

When does heat in steam become latent?

How would you ascertain what amount of water is necessary to ndense a given quantity of steam?

What is low-pressure steam?

Why is the steam of salt water fresh?

State the difference between the latent and sensible heat of am at different pressures.

State the total heat and relative volume of steam at different essures.

As the sensible heat in steam increases, does the latent heat crease?

In what way does the change affect the economy of the steam-gine?

What is meant by the volume of steam?

What is the difference in volume between water and steam at tmospheric pressure?

How much does one cubic foot of steam at atmospheric press-re weigh?

Is the effluent velocity with which steam of different pressures ows into the atmosphere uniform?

State the velocity with which steam at different pressures flows to the atmosphere or into steam of a lower pressure.

What is the objection to carrying steam long distances in pipes part from the first cost of the pipe?

How would you minimize these points as much as possible?

Why are not exhaust pipes covered with a jacket as well as ve steam pipes?

What pressure will saturated steam have if its temperature is 0° F.?

PART III.

BOILERS.

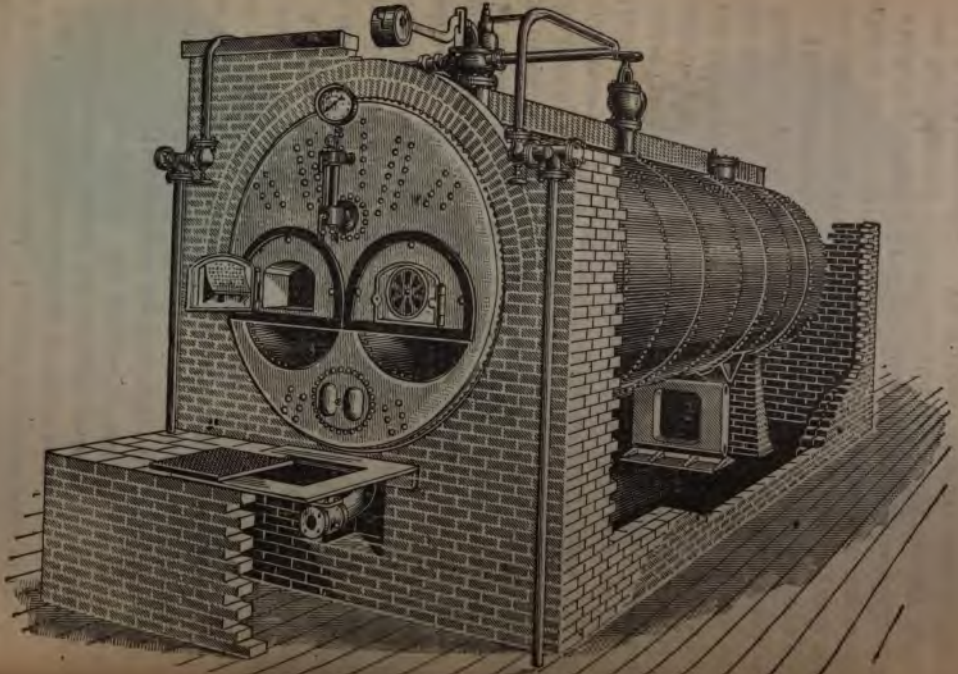
CHAPTER IX.

HISTORICAL AND DESCRIPTIVE.

Plain Cylindrical Boiler.—The first boilers consisted essentially of a plain cylinder of cast iron, set longitudinally in brickwork. The lower part of the cylinder contained the water, the upper part the steam. The ends were usually made hemispherical for increased strength, and the furnace was placed under the boiler at one end, consisting essentially of a series of grate bars set at a convenient distance from the boiler shell.

This type of boiler was in use for many years. It has, however, two great defects. In the first place, the heating surface, consisting of about one-half of the surface of the shell, is much too small compared to the bulk of the boiler, and consequently the gases pass from out of the stack at a very high temperature, wasting a large percentage of the heat of combustion. In the second place, the scale formed in the bottom of the boiler, right where the heat is most intense, makes a non-conducting stratum, which soon renders that portion of the heating surface practically useless, besides having a tendency to burn up the iron at that point. This latter defect has been partially remedied by placing a removable trough in the bottom of the boiler. The other defect, namely, insufficient heating surface, has been sufficient, however, to condemn this type of boiler, and there are very few in use at the present time.

h, Lancashire, and Galloway Boilers.—The next step in *pment* was the Cornish boiler, which consisted of a cyl-

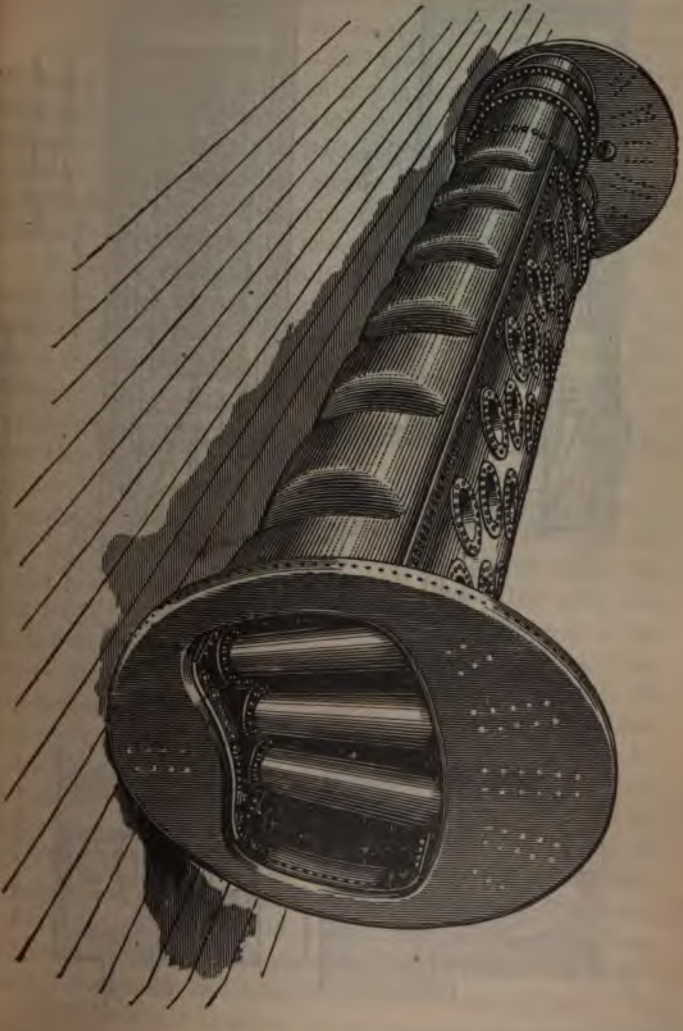


indrical shell with an internal cylindrical flue running the whol length of the boiler. The furnace is contained in the flue, wit the grate bars at one end. In order to obviate some of the defect of this type it has been modified in many ways.

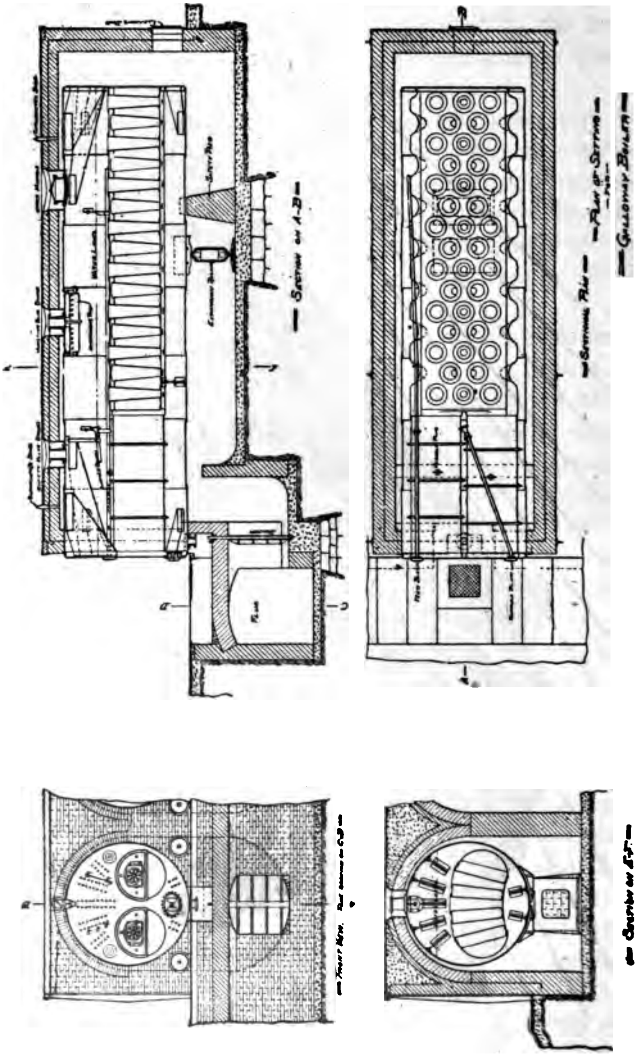
The Lancashire boiler, for example, contains two internal flue placed side by side, for the purpose of attaining a more perfec combustion. The furnaces are fired alternately, and consequentl the smoke and unconsumed gases from the freshly fired furnac are ignited in the common flue (the two flues usually merge int one at the back of the bridge walls) by the heat of the othe furnace.

A further modification of this type is the Galloway boiler, whic is still used extensively. In the Galloway type, which is illu trated in the accompanying cuts, it will be observed, that the are two furnaces placed side by side, merging into a common fl behind the bridge wall. The heating surface is increased by number of conical tubes, called Galloway tubes, through whic the water circulates, and by corrugating the flue as shown. T corrugation of the flue and the Galloway tubes, besides increasi the heating surface, also add strength to the boiler and make sta unnecessary. The first cut shows the internally fired type of t Galloway boiler as it is ordinarily set. The casting below t centre carries the weight of the boiler, and the brick pier imme ately behind it is added for safety, in case anything should ha pen to the casting. The second cut shows the corrugations a the Galloway tubes, while the third is a plan of the settin These boilers are also frequently made with external furnaces.

The advantages claimed by the makers of the Galloway boil are that every portion is easily accessible for cleaning and repair that it is so constructed that the expansion and contraction which it is subjected have practically no deleterious effects; that can be examined while in operation; that it gives dry steam a is safe and economical. All of these claims are more or less bor out in actual practice, and the boiler is certainly a very successf one in many ways.



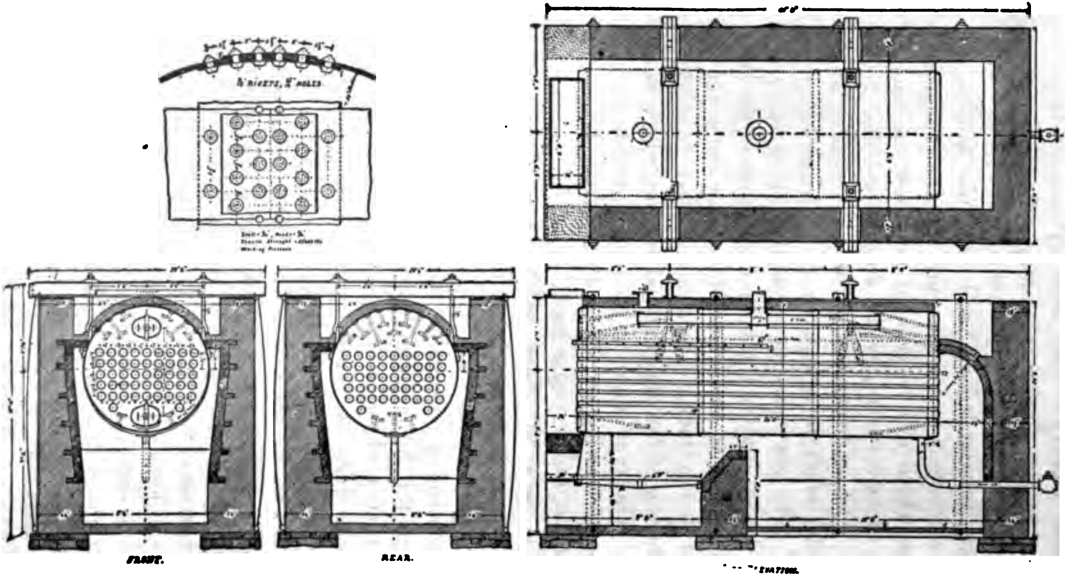
Galloway Boiler Flues.

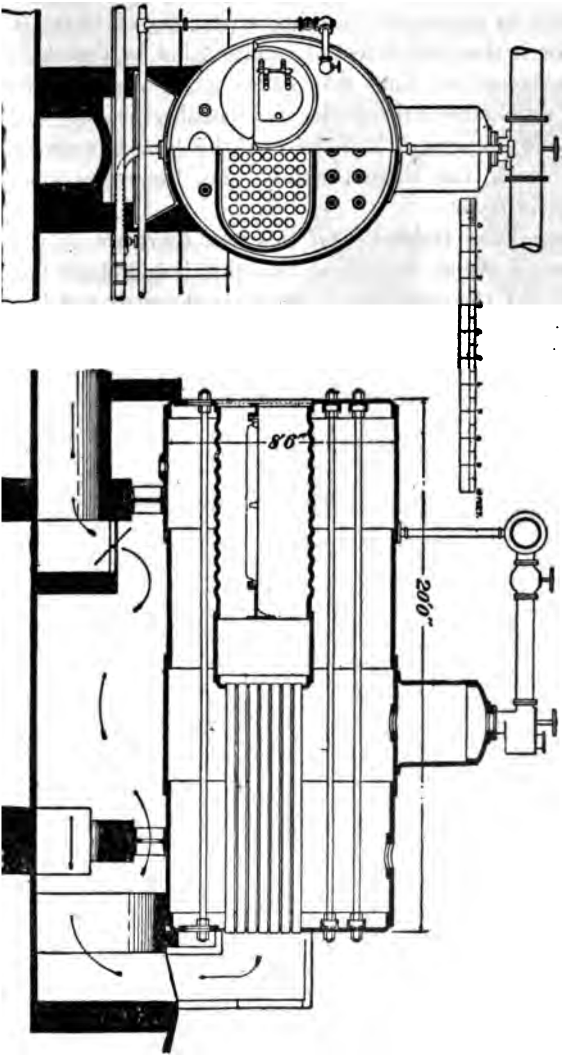


Setting Plan—Galloway Boiler.

ire Tube Boilers.—The plain cylindrical boiler has been
eloped, also, by placing tubes longitudinally within the shell.
s class of boilers, which is commonly known as "tubular boil-
," "return tubular boilers," and "fire tube boilers," is without
ıbt more common to-day than any other, although certain dis-
antages, which will be pointed out below, are causing its dis-
cement, to some extent, by the water-tube boiler for stationary
poses. The annexed cut shows a modern type of return
ular boiler as set in brickwork, the furnace being external to
boiler. The gases passing across the bridge wall travel to the
r of the boiler, heating the bottom and sides of the shell, thence
ough the tubes to the front, where they enter the main flue
l thence to the stack. The steam is taken from the *dry pipe*,
wn at the top of the longitudinal section, which is perforated
the top. The pipe shown at the bottom and to the right is for
purpose of blowing off the contents of the boiler. In other
pects the diagram explains itself.

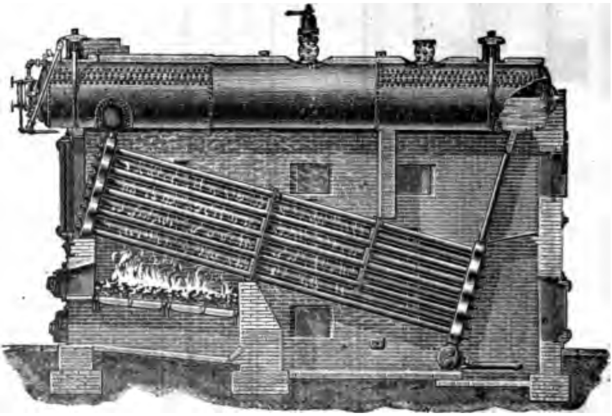
he cut on page 167 shows another form of boiler similar in
ny respects to the above, but internally fired. The main dif-
ences are that the furnace in this type is placed within the
ll and consists of corrugated plates of steel. The gases pass
ectly from the furnace through the tubes to the rear of the
ler, and thence along the bottom and sides to the front, where
y enter the flue. As far as heating surface is concerned, the
ct is practically the same. It will be observed, also, that there
o dry pipe in the top of the boiler, but in its place a dome,
n which the steam is taken. This feature, however, is not pecu-
to either of these two types of boilers. The boiler illustrated
his cut represents the type used by the Philadelphia Bureau of
ter. The following are the principal dimensions: The boiler is 8
6 inches in diameter and 20 feet long. It has 90, 4-inch tubes,
ox's corrugated flues and 12, 2½-inch stay bolts that run from
d to head, as shown, with nuts outside and inside. The boiler
es are ⅞-inch *thick, the heads ⅝-inch*, and flues $\frac{17}{32}$-inch. The
ers are all tested to a pressure of 215 pounds per square inch.


FRONT.
REAR.


8′6″
20′0″
FEET

Tubular boilers have many advantages. They are ea accessible for repairs and cleaning, strong and efficient. The g objection is that any defect or deterioration in the shell whic not discovered in time may cause a serious explosion, wh would wreck the entire boiler and possibly produce fatal res to life and property. Many cases of this kind have been recor and it is for this reason, mainly, that the water tube boile growing in favor.

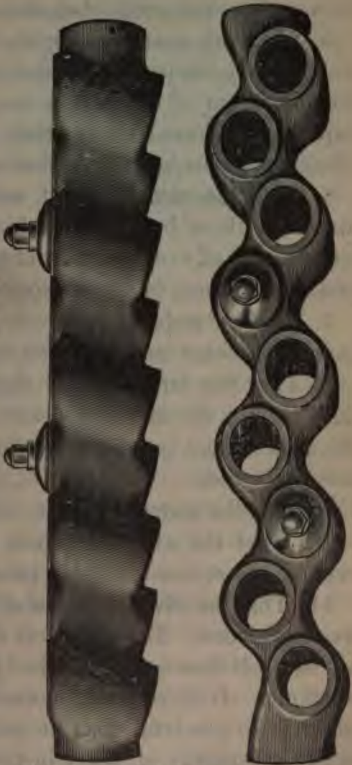
Water Tube Boilers.—Of this class there are so many dif ent types in use at the present time that it is difficult to select to represent the entire class. Perhaps the most widely used, the one which will most nearly represent the entire class, is Babcock & Wilcox, although there are many others which g equally good results. The annexed cut shows this type of boi



Babcock & Wilcox Boiler.

It consists essentially of a series of wrought-iron or steel tu suspended in an oblique position from steam and water drums means of vertical passages at the ends, which also serve to nect the tubes with each other. A mud drum connects the tu rear and lowest point of the boiler. The end connect

rs in this type are in one piece for each vertical row of
e latter being staggered as shown. The ends of the tubes
nded into the headers.



Headers of Babcock & Wilcox Boiler.

er therefore consists of
r of vertical sections of
bes, virtually independ-
ch other, except for the
nections to the steam
drums. The first cut
early how the boilers
he course of the com-
gases, and the level at
e water is carried. For
the plates are removed
ends of the tubes and
g tool inserted. The
steam drums are made
ht-iron or steel, while
rums are usually made
on.

lowing advantages are
or water-tube boilers:

t the portions of the
ich contain the water
nall in diameter that
rial used in the con-
can be made compar-
ght without impairing
gth. Consequently the
ansmitted to the water
dily and the danger of burning the iron where it is ex-
the fire is greatly diminished.

t there are no riveted joints, and consequently no
icknesses *of metal exposed to the fire.*

the draught area, being much larger than in fire-tube boilers, gives ample time for the absorption of the heat of gases before their exit to the chimney.

4. **That the gases** being thoroughly mingled in their pass between the staggered tubes, the combustion is more complete.

5. **That the gases** impinging against the heating surface pendicularly, instead of gliding along the same longitudina the absorption of the heat is more thorough. It is claimed experiments have proven that a gain of 30 per cent. in efficiency of the heating surface is effected.

6. **That the circulation** of water is rapid and all in the direction, there being no conflicting currents. As a result temperature of every portion of the boiler is practically the and the tendency to deposit scale is materially lessened.

7. **That the water** being divided into many small streams in envelopes, steam may be raised rapidly.

8. **That the large area** of disengaging surface in the dru together with the fact that steam is delivered at one end and ta out at the other, insures dry steam without the aid of any su heating device.

9. **That the water level** may readily be kept steady.

10. **That the whole structure** is so flexible that the parts expand and contract without producing strains.

11. **That the division of water** into small masses avoids des tive explosions. The diameters of the parts subjected to pre are so small that even if made light their power to resist rup is ample. It is claimed, moreover, that the circulation of water is so powerful that no part will be uncovered to the until the quantity of water in the boiler is so far reduced th overheating should occur no explosion could result.

12. **That the space** occupied by this type of boiler for a g power is much less than in fire-tube boilers.

13. **That, by a suitable arrangement** of hand and man every part of the boiler is accessible for cleaning and repairs.

14. That the **loss of effect** from dust collecting on the to *the tubes is* far less than in fire-tube boilers, where it colle terior. In the latter case there is no limit to the amount st which may collect, while in the former only a limited t is retained.

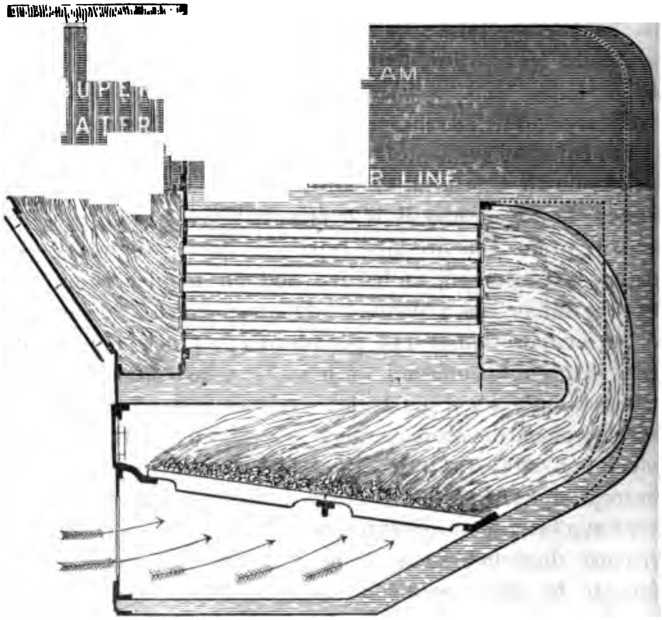
That since no part of the boiler above the water level is ed to the fire, and because of the absence of deteriorating s and of thick plates and joints in the fire, it is much more le.

That, being made in sections, it is less cumbrous and more easily transported. In fact, the parts for a boiler of considerable capacity can be made small enough for mule ortation.

That a new tube may be easily inserted or almost any other made by an ordinary mechanic without any but ordinary

mmary.—The advantages which have just been enumerated ter-tube boilers are all more or less borne out by practical ience with this type of boiler. They should not be over-ted, however, and it is a fact that many intelligent engi- still prefer the fire-tube type. As far as the economy of tion is concerned, we believe that for regular running the tube boiler has a distinct advantage over the return tubu- An evaporation of 11½ pounds of water per pound of com- le is not at all unusual, while in fire-tube boilers such results tained only when the boiler is new or just after it has been ghly cleaned. Moreover, it is certainly a fact that, from the oint of safety, the water-tube boiler is distinctly better. Some explosions which have occurred in connection with fire-tube have been most disastrous to life and property, and their ence does not seem to be growing less frequent. Ex- ns, to be sure, are not an impossibility in the other type, onsidering how many are in use, they are very rare, and, ver, an explosion in a water-tube boiler, if properly set, sel- wrecks more than a single tube or a header. On the hand, the *water-tube boiler* is a much more expensive *tus than the fire-tube, especially* for small capacities, and this feature alone will, without doubt, cause the latter to be tained in many cases, notably in the coal regions, where the c of fuel is so low as to make economy in its use a secondary c sideration.

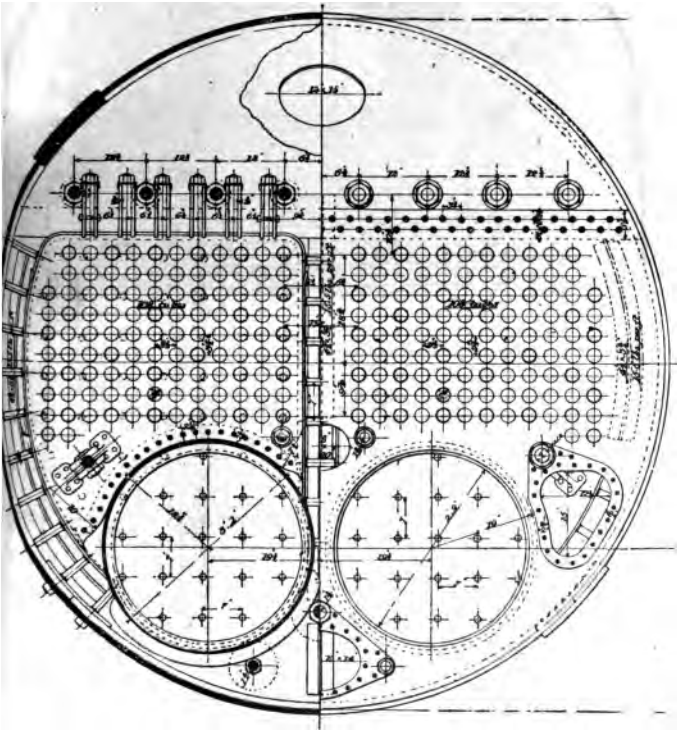
Marine Boilers.—For marine purposes many types, both f and water tube, are used. The water tubular is fast disappeari and is now rarely to be found except in the United States Na and in the navies of other countries. Its gradual disappearan arises from the fact that it is more expensive to build and repair, is more complex, and requires extra care and manag



Fire-Tubular Marine-Boiler.

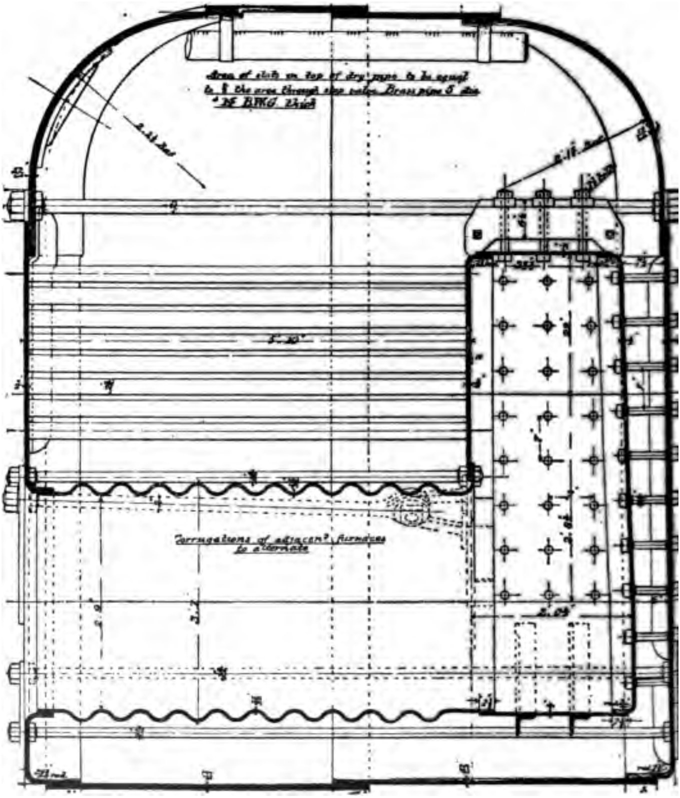
ment. If a tube splits or becomes leaky in the fire-tubular boi *the difficulty may be met by plugging, and the vessel can proc on its way; but if* the same accident occur in a water-tubula ld be necessary to blow out the boiler. The same principle which embodied in the Montgomery water-tubular marine-boiler was oduced into the Dimpfel locomotive-boiler, but soon fell into se in both cases. The fire-box, fire-tubular marine-boiler, h combustion chamber at the back end is the type of marine ler most commonly used at the present time.

The auxiliary boilers of the United States battleship, Nos. 1, nd 3, the construction of which is clearly shown in the accompying cuts, illustrate modern marine boiler practice.



Auxiliary Boilers. Battleships Nos. 1, 2, and 3.

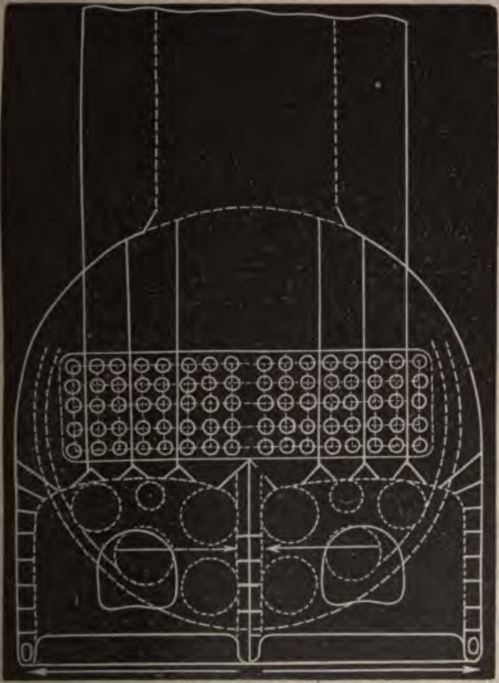
In this boiler it will be seen that there are two internal corr gated furnaces, which is the number usually employed when tl diameter of the boiler is from 9 to 13 feet. For diameters ov 13 feet three are often used, while the largest boilers, often excee


Area of slots on top of dry pipe to be equal
to ⅞ the area through stop valve. Brass pipe 5" dia.
BWG thick
Corrugations of adjacent furnaces
to alternate

Auxiliary Boilers. Battleships Nos. 1, 2, and 3.

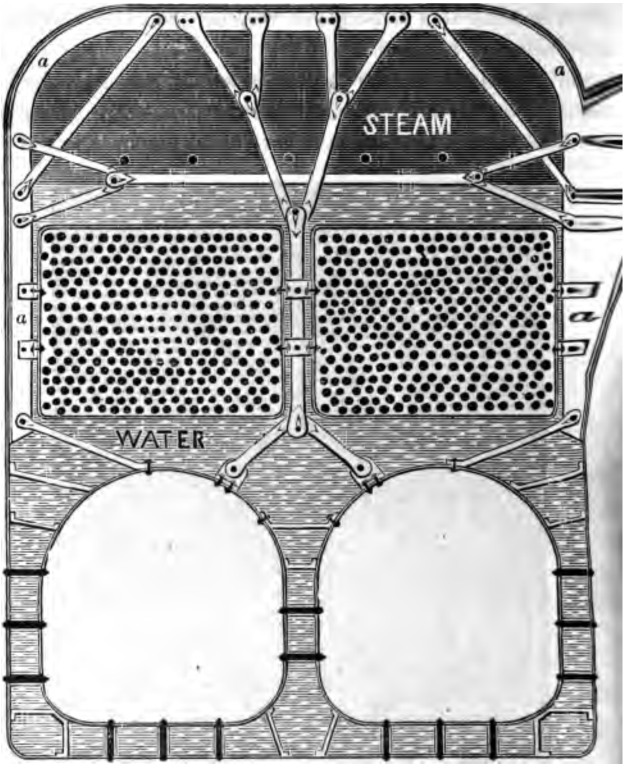
ing 15 feet in diameter, have four furnaces. Moreover, this t of boiler is frequently made double-ended, in which case there furnaces at both ends, each furnace having a separate combus nber, so that if a tube gives way in one chamber the other aces are not affected.

lartin's upright tubular boiler is sometimes used for marine poses. Its only advantage is economy of space; its first cost ore than that of the ordinary horizontal marine tubular boiler. d it is not more efficient. The capacity of the steam-room is one-third the capacity of the boiler.



Direct Flue and Return Tubular Marine-Boiler.

This type of boiler is now but rarely used, and, in fact, none of s which have been tried from time to time have proved *superior to the cylindrical* return tubular type with



The above cut represents the arrangements most generally
ployed for bracing marine steam-boilers, and includes the vert
and horizontal, angle, toggle, dome, and crown braces; as wel
the buckles, crow-feet, angle-irons, girths, stay-bolts, and leg bra
The tubes answer for braces for the tube-sheets; the crow-feet
the crown and dome; the proper strength for the braces of mar
boilers may be found by multiplying the number of square in
exposed to the pressure of the steam by six times the steam-p
ure to be carried.

Principal dimensions of the boilers illustrated in the pages 173 and 174 are as follows:*

Diameter of boiler, outside		10′ 1$\frac{25}{32}$″
Length " "		8′ 6″
Length of grate		5′ 10″
Heating surface:		
Tubes	824.66 sq. ft.	
Furnaces	60. "	
Comb. chamber	84. "	
Total	968.66 sq. ft.	
Grate area		32. sq. ft.
Ratio of heating to grate surface		30.3
Boiler pressure		160. lbs.
Number of tubes		216 { 58 stay. 158 ordinary.

omotive Boilers.—The duties which a locomotive boiler is upon to perform have led to a development distinct, in respects, from other types of boilers. A boiler which is to l on a locomotive must have the following properties:

size and weight are limited, because the boiler must be along at a high rate of speed. For the same reason and account of the jarring to which a locomotive is subjected, etting cannot be considered. Consequently the boiler must rnally fired. Additionally, it is necessary to evaporate a nsiderable amount of water in a short time and to carry it h pressure. In other words, the conditions are such that elopment of this class of boilers has been in the direction l steaming rather than in that of economy.

ocomotive type of boiler is illustrated in the accompany-s. The two sectional elevations † represent two different he "Crown Bar" and "Radial Stay," so called after the

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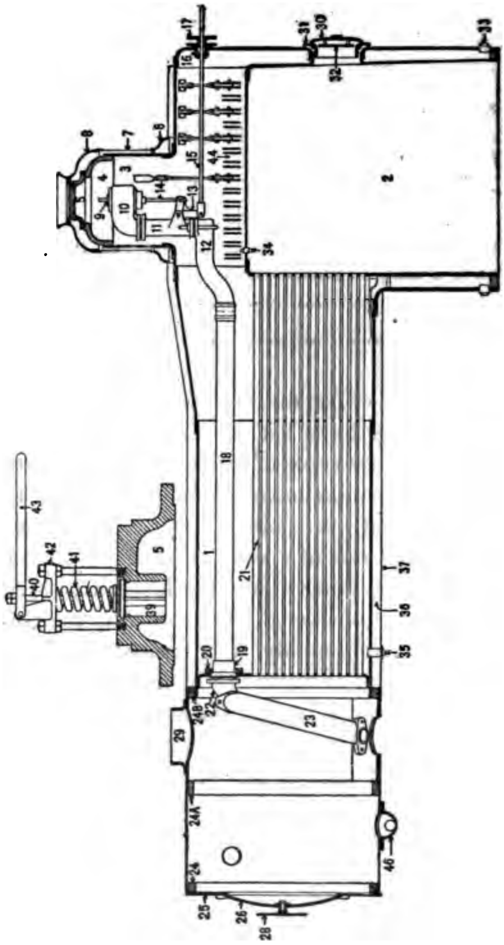
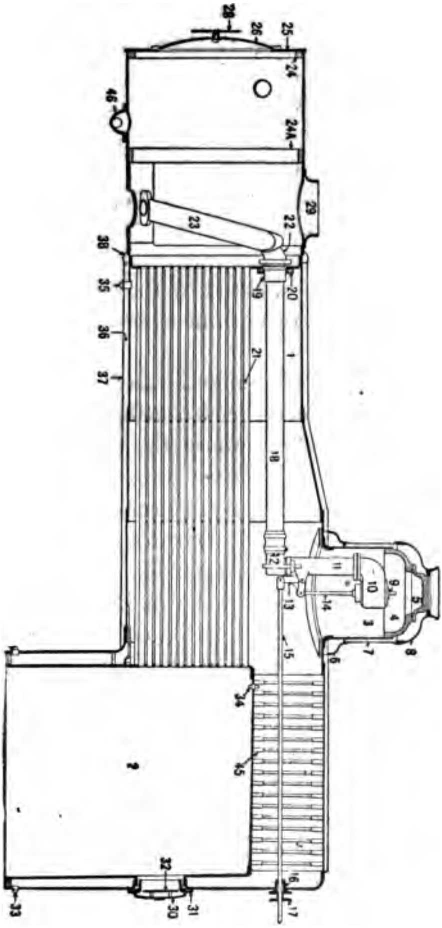
ı the "Report of the Chief of the Bureau of Steam Engineering," ton, D. C., 1890.

ı "*Illustrated Catalogue of Narrow* Gauge Locomotives," Baldwin *ve Works, Philadelphia, 1897.*

2



CROWN BAR TYPE.



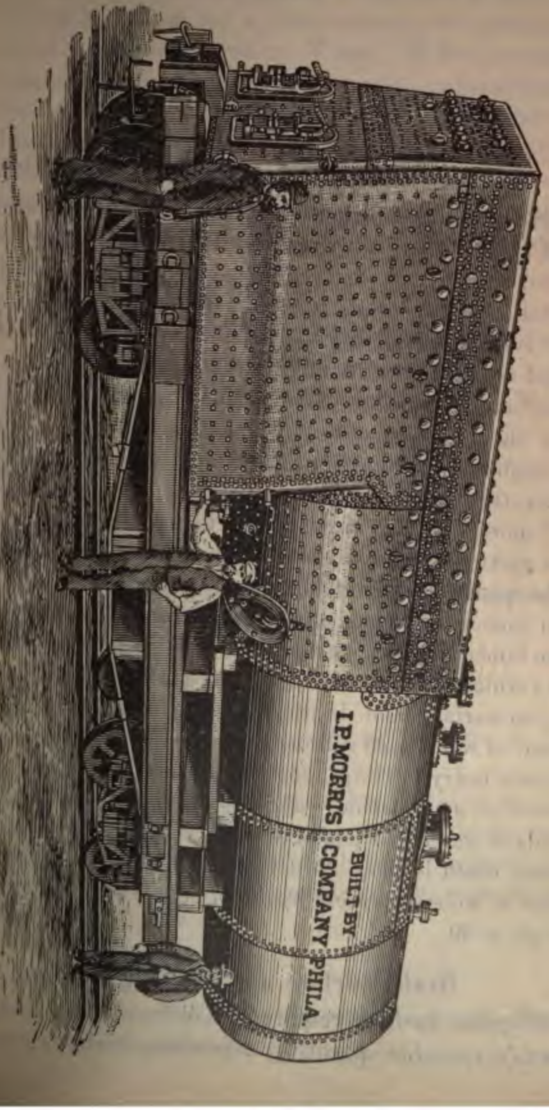
RADIAL STAY TYPE.

methods of staying the furnaces, as is clearly shown in th In these diagrams 1 is the boiler proper, 2 the firebox, steam dome, and 18 the dry pipe, 9 is the throttle valve, smoke-box front with door 26, 30 is the fire-door, 39–43 the valve, 44 the crown bars and stay bolts.

The furnace or fire-box is often made of copper plates. part of the boiler is usually rectangular, strength require the plates shall be comparatively thick and it is in orde they may transmit the heat from the furnace readily tha are made of copper. The gases pass through a series o tubes of small diameter to the stack which is supported base 29. The draught is assisted by the exhaust steam fr cylinders, which is discharged from a nozzle (not shown) the stack.

The locomotive type of boiler is used quite extensive stationery purposes wherever brick setting is undesirable count of weight or vibration, where the boiler is to be po or where rapid steaming is of more importance than econ the use of fuel. These boilers are usually built by mak stationery fire-tube boilers and their design does not differ rially from the regular locomotive boiler.

The Bellpaire fire-box boiler, shown in the perspective is a stationary boiler, which is built on the same general This type of boiler was adopted at the Calumet and Hecla on account of the excessive vibration to which it is con subjected and which makes brick settings impracticable. Bellpaire boiler contains two furnaces connecting into a cc chamber and 200 3″ tubes 16 feet long. The shell of the proper is made of $\frac{3}{4}''$ steel plate, while the firebox, etc., a $\frac{9}{16}''$ thick and stayed very extensively, as can be seen in th tration. The boiler carries 180 pounds pressure.



Bellpaire Fire-box Boiler.

CHAPTER X.

BOILERS.—DESIGN AND CONSTRUCTION.

Horse-power.—The horse-power of boilers is now usually d mined by what is known as the *Centennial Rating,* which adopted in 1876 by the committee of judges of the Centen Exhibition. According to this, a horse-power is 30 pound water evaporated into dry steam per hour, from feed water at 1 F., and under a pressure of 70 pounds per square inch above atmosphere. A boiler rated at any stated number of ho power should be capable of developing that power with easy ing, moderate draught, ordinary fuel, and good economy; further, the boiler should be capable of developing at least third more than its rated power to meet emergencies at ti when maximum economy is not the most important considerat

The quality of steam that can be generated in any boiler i given time is dependent on a great variety of circumstances, as the kind of boiler; its condition as to scale, dirt, etc.; the n ner in which it is set and fired, the quality of fuel used, am of grate-surface and heating surface, draught, etc., while amount of water used will depend entirely on the engine, prov the steam is dry. The evaporation in tubular boilers,—station locomotive, and marine,—under good conditions, is about 8 t pounds of water to 1 pound of coal; water-tube, 10 to 12; bu average result is about 25 per cent. below this. The nominal of fuel in boilers is rarely less than 30 per cent., and is freque as high as 50.

Grate Surface and Heating Surface.

***The grate surface* required** in different types of boilers i *extremely variable* quantity, depending chiefly upon the qu and the draught. If the quality of the coal is good, the age of ash being low, for a given draught, the grate may ller than for a poorer quality of coal. If the percentage is high, the grate surface must be made proportionately

The following table, taken from Kent's "Mechanical ers' Pocket Book," gives approximately the grate surface d under different conditions. In general it may be said designing a new boiler, the grate surface should be made as s possible without incurring other disadvantages in the design.

TABLE OF GRATE SURFACE PER HORSE-POWER.

	Lbs. Water from and at 212° per lb. Coal.	Lbs. Coal per H. P. per hour.	Pounds of coal burned per square foot of grate per hour.								
			8	10	12	15	20	25	30	35	40
			Square feet grate per horse-power.								
coal and	10	3.45	.43	.35	.28	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
coal and	8.61	4	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
coal or	6.9	5	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
ite and iler.	3.45	10.	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

mple.—With a poor quality of coal what should be the size te for a fifty-horse power boiler? What would be the con- on of coal, and how much water would be evaporated per of coal, the consumption of coal being 20 pounds per foot of grate per hour?

n the table above:

re feet of grate = 29 × 50 = 14.5.

nds of water *from and at 212°* = 6 pounds per pound of coal.

ds of coal per horse-power per hour = 5.75.

The ratio of heating surface to grate surface is depend largely upon the quality of coal which is to be used. For go anthracite coal the practice, in stationary boilers, is to make th ratio from 30 to 40 square feet heating surface to 1 square fo grate surface. For bituminous coal the ratio is much high especially where the quantity of coal to be consumed per squa foot of grate is large. In this case the ratio is sometimes as hi as 60 to 1. There seems, however, to be a very considerab difference of opinion among engineers in this respect. While generally agree that, in proportioning a marine boiler, example, there should be sufficient grate-surface to consume th maximum quantity of coal required for the engine for which th boiler was intended to furnish steam, and that there should sufficient heating surface to absorb the heat evolved by the fu yet, when it comes to laying down proportions, one engine allows twice as many square feet of heating surface to one squa foot of grate surface as another. Watt's proportions for land a marine boilers varied from 9.5 to 10 feet of heating surf to 1 square foot of grate surface. Maudsley and Miller allow 10 square feet of heating surface to 1 square foot of grate surfa in the boilers of the celebrated ocean steamer Great Weste and from 10 to 12 square feet of heating surface to 1 square fo of grate surface in other marine boilers that they construct about the same time; so that neither they nor Watt seemed have any fixed rule, nor did there appear to be any amo naval constructors either in this country or in England.

This may be seen from the fact that the U. S. gun-boat Ma [illegible] feet of heating-surface to 1 square foot of gra [illegible] same-sized engine, had only 16 to [illegible] had 66 square feet of heati [illegible] grate-surface, while the Franklin [illegible] capacity, with engines of the sa [illegible] of the celebrated steamshi [illegible] made such fast time betwe [illegible] square feet of heating-surf

. square foot of grate-surface, while in the boilers of the steam-
s of the Cunard Line the heating-surface varies from 18 to 37
are feet to 1 square foot of grate-surface. The Mary Powell,
of the fastest river-boats in American waters, has 17 square
t of heating-surface to 1 square foot of grate-surface. In pro-
rtioning the heating-surface to the cubic contents of the cylinder,
e same variation seems to exist which shows there is no recognized
oportion for either. The steamship Massachusetts, U. S. N., has
square feet of heating-surface to 1 cubic foot of cylinder, while
e Powhatan has less than 15 square feet, and the San Jacinto has
trifle over 12. The merchant-steamer Union had one hundred
d eighteen square feet of heating-surface to 1 cubic foot of
linder, while the Isaac Newton had only 10 to 1. The steam-tug
scue had 63 square feet of heating-surface to 1 cubic foot of
linder, while the Anglo-Saxon had only 10 to 1.

The average proportion of heating-surface to grate-surface of
5 steamships, tugs, and ferry-boats examined was about 30
uare feet of heating-surface to 1 square foot of grate-surface,
ile an examination of a great number of steamships, tug, and
ry-boats in this country, England, and France, showed that the
erage proportion of heating-surface to 1 cubic foot of cylinder
s about 28. In stationary boilers the heating-surface varies
m 12 to 30 to 1 square foot of grate-surface, while in some
tented sectional boilers there are 60 to 70 square feet of heat-
-surface to one square foot of grate-surface, the average for
omotive-boilers being about 60 square feet of heating-surface
1 square foot of grate-surface.

To proportion a marine-boiler understandingly, it is necessary
know the size of the engine and of the boat or ship, the load
be propelled, and the speed at which it is to move. The engi-
r can determine the pressure and volume of steam required,
d decide on the degree of expansion, the quantity of grate- and
ting-surface, and in relation to these two latter conditions, as
wn in the *foregoing paragraphs,* the field has a very wide lati-
le. But he must be sure that the boiler possesses sufficient

strength to resist in safety the maximum pressure to which it ever be exposed; that it contains sufficient grate-surface for combustion of the necessary quantity of fuel under any cir stances; that it has sufficient heating-surface to evaporate the essary quantity of water; that it is capable of containing a cient supply of water and steam to prevent undue fluctua and that it affords convenient facilities for the repair or ren of any of its parts. After the foregoing conditions are determ on, another object of great importance to be considered is mal the boiler as light and compact as possible. The term hea surface, when applied to steam-boilers, means all that part of fire-box, crown-sheet, tube-sheets, and flues with which the fire flame come in contact in their escape from the furnace to chimney.

Rules.

Rule *for finding the number of square feet of heating surface tube, or any number of tubes.*

Multiply the circumference of the tube in inches by its le in inches, and *divide by* 144; the quotient will be the numbe square feet of heating surface. This *multiplied* by the whole n ber of tubes, will give the aggregate amount of heating surfa

Rule *for finding the heating-surface of fire-box boilers—locomo marine, or stationary.*

Multiply the length of the furnace-plates in inches by t height above the grate in inches; multiply the width of the in inches by their height in inches; multiply the length of crown-sheet in inches by its width in inches; also the combi circumference of all the tubes in inches by their length in inc from the sum of these four products subtract the combined are all the tubes and the fire-door; divide the remainder by 144, the quotient will be the number of square feet of heating-surf

Rule for flue-boilers.—Multiply $\frac{2}{3}$ of the circumference of *shell in inches* by its length in inches; multiply the combi *rcumference* of all the flues in inches by their length in inc ide the sum of these two products by 144, and the quotient l be the number of square feet of heating-surface.

Rule for cylinder-boilers.—Multiply ⅔ of the circumference the shell in inches by its length in inches, divide by 144, and quotient will be the number of square feet of heating-surface.

Rule for externally-fired tubular boilers.—Multiply two-thirds the circumference of the shell in inches by its length in inches; ltiply the combined circumference of all the tubes in inches their length in inches. To the sum of these two products add o-thirds the area of both tube-sheets; from this sum subtract the mbined area of all the tubes; divide the remainder by 144, and e quotient will be the number of square feet of heating surface.

Rule *for finding the heating-surface of vertical tubular boilers, such are generally used for fire-engines.*—Multiply the circumference the fire-box in inches by its height above the grate in inches. ultiply the combined circumference of all the tubes in inches their length in inches, and to these two products add the area the lower tube- or crown-sheet, and from this sum subtract the ea of all the tubes, and divide by 144. The quotient will be e number of square feet of heating-surface in the boiler.

Strength of Boilers.

Rule *for finding the pressure per square inch which will rupture ylindrical boiler.*

Multiply the thickness of the shell in inches by the tensile ength of the material and divide the product by one-half the meter of the boiler in inches.

Example.—Suppose the diameter to be 6 feet and the thickness the shell to be ½ inch, then if the tensile strength of the mate-l is, say, 48,000 pounds per square inch, the bursting pressure ll be

$$\frac{\frac{1}{2} \times 48000}{\frac{1}{2} \times 72} = 666\tfrac{2}{3} \text{ pounds per square inch.}$$

In the above it has *been assumed that* the shell of the boiler is *ontinuous ring without joints of* any kind. In practice this is of course impossible. In all modern boilers the shell is bui of a number of plates riveted together.

Riveted joints weaken the shell and their effect is usually t into account in the calculations by assuming that the te strength of the material has been impaired to a certain ex depending on the nature of the joint. The following table densed from Unwin's "Elements of Machine Design," g approximately, the extent to which the plate is weakened u different conditions. The figures apply to iron plates and rivets:

Thickness of plates.	Diameter of rivets.	Pitch of rivets.	Efficiency of joints.
SINGLE RIVETED JOINTS.			
3/8″	3/4	1 7/8	.606
1/2″	7/8	2	.571
5/8″	15/16	2 1/16	.543
3/4″	1 1/16	2 3/16	.521
1″	1 1/4	2 5/16	.485
DOUBLE RIVETED JOINTS.			
3/8″	3/4	3	.75
1/2″	7/8	3 1/8	.72
5/8″	15/16	3 3/16	.71
3/4″	1 1/16	3 5/16	.69
1″	1 1/4	3 1/2	.64

In using this table the tensile strength of the material is multiplied by the efficiency of the joint.

Example.—If in the example given above the joint is d riveted, what would be the bursting pressure?

$$\frac{\frac{1}{2} \times 48000 \times .72}{\frac{1}{2} \times 6 \times 12} \quad 480 \text{ pounds per square inch.}$$

The result of this example does not mean that the boiler be worked at 480 pounds per square inch. To find the wor pressure it is usual to assume a factor of safety, which mea number by which the tensile strength is divided before it is in the calculations.

The factor of safety used in boiler calculations differ

in different localities. For example, the number adopted
British Board of Trade for marine boilers is 5, while the
h government uses 3 for stationary boilers. Hence we have
llowing

le *for finding the working pressure in cylindrical boilers.*

ltiply the thickness of the shell in inches by the tensile
th of the material and the efficiency of the joint. Divide
esult thus obtained by the product of one-half the diameter
boiler in inches and the factor of safety. The quotient will
e safe working pressure in pounds per square inch.

ample.—What is the safe working pressure in a cylindrical
with double riveted joints, if the diameter is 8 feet, the
ness ¾ inch, the factor of safety 4, and the tensile strength of
ate 50,000 pounds per square inch?

$$\frac{\frac{3}{4} \times 50000 \times .69}{\frac{1}{2} \times 12 \times 8 \times 4} = 136 \text{ pounds per square inch.}$$

le *for finding the proper thickness of cylindrical boiler shells to carry a given pressure.*

ltiply the working pressure in pounds per square inch by the
of safety and one-half the diameter of the boiler in inches.
e the result thus obtained by the product of the tensile
th of the plate and the efficiency of the joint. The quotient
e the proper thickness in inches.

mple.—Required the proper thickness of shell of a cylindri-
iler with double riveted joints to safely carry a working pres-
f 125 pounds per square inch. Diameter, 65 inches; factor of
, 5; tensile strength, 45,000 pounds. As the proper thickness
e about ⅝″, we will assume .71 as the efficiency of the joint

$$\frac{125 \times 5 \times 32.5}{45000 \times .71} = \tfrac{5}{8}'' \text{ approximately.}$$

e *for finding the safe external pressure on boiler flues.*

ltiply the square of the thickness in inches by the constant
er, 89,600. Divide the product by the length of the flue in
d by *its diameter in inches.* The quotient will be the safe
g pressure in pounds per square inch.

Boiler-stays.

Boiler-stays, in any case, are but substitutes for real stren in the shell or other parts of the boiler. The strain usu allowed on them per square inch is about 5000 pounds. The common method of securing them is to cut a thread on both and screw and cold-rivet them into the plates; another me is to flatten the ends of the stay, and secure them to the b by means of one or two rivets; still another is to rivet eye-b into the shell of the boiler, fork the end of the stay-bolt, attach to the eye-bolt by means of a cotter. But all the for ing methods have their objections, as, when the stays bec slack, and it becomes necessary to make them taut, the nece of cutting away the rivets, destroying the thread, and weaken the boiler is necessarily involved.

The most modern and permanent method of securing stays the shell or ends of steam-boilers is by riveting angle-iron the parts to be braced, as shown at *a, a, a, a,* in the cut on 176, and drilling holes in the angle-irons where the brace is to attached. Then the rods may be forked, and attached to angle-irons by means of a cotter, which term means a blank b with a splint in its end, which may be expanded with a cold-ch to prevent them from coming out. This arrangement has advantage, that, where the braces become slack, they may made taut by taking them out, heating them in a forge, and setting them. The value of stays as a substitute for strength safety depends very materially not only on the manner in wh they are attached to the parts they are intended to strengt but also on their position, which affects their ability to stand sile strain and compression-pressure. If the stay is prop anchored, it will stand, on a straight pull, a resistance equal tensile strength, or it will resist the force of compression equa *its crushing* strength; but if it stands slightly oblique, its po *of resistance* will be very much diminished.

Stay-Bolts.

Stay-bolts are the means usually employed to strengthen the t surfaces in the fire-box and water-legs of locomotives and rine-boilers; they are generally screwed into both plates, on ch side of the water space, and riveted by the process called ld riveting. Numerous ordinary-sized bolts are preferable to a w large ones. The difficulty in the case of stay-bolts does not ise ordinarily from tensile strength, brought upon the bolt by e steam-pressure, but from relative changes in position of the o sheets through which the bolt passes, caused by a difference the temperature of the two sheets, and the consequent difference expansion. For instance, if the side sheet of a fire-box of a comotive- or marine-boiler expands in a vertical direction ⅛ of inch more than the outside sheet, then all bolts in the top row ll have their inner ends forced upwards from their original sition to that extent, and the boilers must spring or bend ac-rdingly; whereas, when both sheets become again of the same mperature, the ends of the bolts are drawn back to their original sition.

TABLE

HOWING THE BREAKING STRAIN OF IRON AND COPPER STAY-BOLTS.

	Breaking Weight in Pounds.	Strength distributed over 25 inches area would give Lbs. per square inch.	Strength distributed over 16 inches area would give Lbs. per square inch.
. Iron into iron screwed and riveted	25,000	1,000	1,563
. Iron into copper screwed and riveted.	21,400	856	1,338
. Iron into copper screwed only	*16,200*	648	1,013
. *Copper into copper screwed and riveted. . . .*	14,400	576	900

Boiler Materials.

Boiler making now holds an important place among the m
ical arts. Its progress has been aided chiefly by the enc
growth of the steam-engine as the prime mover, by the inc
facilities afforded for procuring suitable materials, and by i
provements made in working them. In the early days
steam-engine, boilers of copper and cast-iron were used for
ating steam, but they were seldom subjected to a pressure
than that of the atmosphere; but when pressures of 3 to 4 o
7 atmospheres came into use, cast-iron was found to be unr
and treacherous, for which reason it was discarded in fa
wrought iron, which was not employed at first, in conseque
the difficulty found in working it and in making steam-tight
It has, however, of late years become the material employed
almost entire exclusion of cast-iron and copper. Steel, also, i
ing in favor and is now extensively used both for tubes and

The first quality to be sought for in boiler materials is st
This does not necessarily imply the mere power to resist
torn asunder by a dead weight, as in a testing-machine; b
quality to withstand, without injury, the varying shock
strains to which boilers are exposed. An inferior quality o
cannot be relied upon to bear the ordeal of heating and
repeatedly, as they invariably warp and twist, showing de
manufacture; more especially in the process of cold bendin
minute fractures often occur on the outer surface of the pl
stubborn or inferior qualities of iron.

The defect most commonly revealed in working boiler-p
want of lamination. This defect arises from the imperfect
of the several layers which make up the thickness of the pl
is usually caused by interposing sand or cinder, which h
been expelled by hammering or rolled out during the pr
manufacture. This is more frequent in thick than in thin
and is sometimes very difficult to detect in cold plate, a
en discernible in the hot. It also often happens that
h are passed as quite sound, on careful external exa

found to be severely laminated when subjected to heating and
mering, and prove totally unfit for use.

Blisters are of a similar nature, and arise from the same cause
lamination. Sometimes they appear as mere surface defects,
l are of no consequence; but their appearance may be an in-
ation of want of care or skill in the making of the plate, and
uld always excite suspicion. It frequently happens that these
ects pass undetected after the closest scrutiny and test by ham-
ring, but disclose themselves soon after the boiler is set to work,
ecially if the plates be exposed to sudden variations of tem-
ature. In the plates over the fire-grate of an externally fired
ler, such a blister may prove a very serious defect, and often
essitates the cutting out and replacement of the sheet. Infe-
r brands of iron will rapidly show unmistakable signs of weak-
s when placed under the trying ordeal of bearing the alternate
pingement of a fierce flame and currents of cold air. The
id variations of temperature caused by the sudden and frequent
nings of the furnace door, and passage of cold air through the
te-bars, will soon tell on even the best iron, but more quickly
that of an inferior brand.

Characteristics of boiler-iron when broken. On breaking a
te or bar of wrought-iron, the fracture presents an appearance
which the quality of the iron may, in some measure, be deter-
ned. The fracture is designated, on the one hand, as fibrous,
gh, silky, close-grained, etc., or, on the other hand, crystalline,
rse, open-grained, brittle, and cold-shut. When broken sud-
ly, the best qualities of plate and bar iron exhibit a fine,
e-grained, uniform crystalline fracture, even silky, of a light
er color; the appearance in the harder descriptions approach-
to that of steel. The appearance of indifferently refined and
rior qualities is coarser, usually of a darker color, more or less
ven, or open, exhibiting large facets, and approaching some
criptions of cast-iron. When broken gradually, good iron
sents a well *drawn out, close fibre,* of light greenish hue, whilst
rior qualities give a shorter, more open, and darker fibre.

When good ductile iron is gradually torn asunder, it stretc to a considerable extent, causing a diminution of sectional are the fractured part, which should always be compared with t original sectional area of the specimen in judging of the quali An inferior bar or plate may bear as great a tensile strain a similar specimen of superior quality; but on comparing their fr tured areas, it will generally appear that the latter has been dra out considerably, whilst the inferior specimen, having stretc but little, has not sensibly diminished at the fracture. Thi owing to the fact that good ductile iron, when sudden strains occ will stretch, while badly refined will snap. Wrought-iron chan from fibrous to crystalline, after enduring long-continued c hammering, vibration, tension, jarring, and other strains, after lo exposure to the influence of heat, or alternate expansion and c traction whenever it has been used for the plates of a boiler f nace. Even the very best plates, after from ten to twenty ye use in a boiler, have frequently been found to break with stretching, at the same time displaying a crystalline fracture.

It has been said that this shows that a change has taken pl in the nature of the material, and that, from being fibrous a tough, it has, by some unexplained cause, become crystallized a brittle, or that it has lost its nature in consequence of the tre ment it has undergone, whatever that may have been. There no doubt that the strains and other causes above mentioned ha a tendency to make good iron become brittle and liable to sn suddenly under the same treatment that would originally ha torn it gradually, and to this extent a change is produced in nature. This snapping, and not the fatigue of the metal, is t direct cause of the crystalline fracture, which is but a necess consequence of the suddenness of the breaking, and not a pr erty of the iron itself. To say it snaps readily because it has come crystalline is to confound the cause with the effect. It erroneous to say the fibrous nature has passed out of the iron, *its ductility* can to some extent, at least, be restored, in mo *cases, by simply* heating to a bright red, and slowly cooling, a, or, failing that, by hammering or rolling it while hot. By ting to redness, and suddenly cooling, a piece of wrought-iron, will become liable to snap, producing the same effect as cold mmering. The explanation of this is not clear, and it may be ing to the loosening of the crystals into which the composition the material ultimately resolves itself. To this cause may also attributed the same tendency to snap after long-continued jarg or alternate expansion and contraction.

It may be asserted, without fear of contradiction, that all boiler-te worthy of the name is fibrous; whether its hardness makes iable to snap, and, therefore, appear crystalline, depends on its ginal character and the treatment it has undergone. No fine n can, however, by any treatment, except burning, be made to ear coarse, and the fibres of the poorest descriptions of iron not, without refining, be made to appear fine and close-grained. om a want of knowledge of the above facts, false opinions are n expressed respecting the qualities of boiler-plates.

It is no unusual thing to find intelligent mechanics and boiler-kers expressing their opinions, at coroners' inquests, on the ality of the iron in exploded boilers, without anything to base ir opinions on except the load per square inch required to tear e plates asunder. They seem to forget, if the boiler be an old e, that the age, the position in the boiler in which the rent has ten place, the amount of strain to which it has been exposed, d all the circumstances connected with the occurrence, should known in order to decide understandingly as to the quality of iron. It has been shown, in numerous instances, that good duc- iron can be made to appear crystalline when pulled asunder the testing-machine, by confining the minimum sectional area ere fracture will occur to one point or to a very short length.

The general conclusions with regard to boiler material, which y be regarded as established from experiments, observations, l practice, thus far seem to be, 1st, That the laws of resistance the parts *of boilers to the internal* pressure are sufficiently l *established; 2d, It is of the* utmost importance that the ma-

terials employed should be of the best quality as regards stre
and durability; and as there are but few manufacturers of bo
plates, the inspection of materials, especially boiler-plates, sh
be made by competent persons, appointed for that purpose, at
place of manufacture, which inspection should extend to
qualities of ores and the process of manufacture, the requ
brands, stamps, or certificates being put on or authorized by
inspectors in person. There is much greater certainty of secu
the best materials by an inspection of the process of working,
of the raw materials employed, than by an inspection of p
after they have been sent to market, when, judging from all e
nal appearances, good and bad plates are not easily distinguis

Practical limits to the thickness of boiler-plates.—The pr
strength of boilers, in order to enable them to withstand
safety the required pressure of the steam, is a matter of n
importance as regards both life and property, and the resp
bility of the proprietors and constructors of boilers is of so g
a character as to justify the devotion of a much larger spac
this subject than is convenient in this work. The principle
which the strength of the material depends may be expresse
a very few words,—the strength being directly as the thicl
of the metal, and, inversely, as the diameter of the boiler.

So long as the quality of boiler-iron remains as it is at pre
the thickness of the plate may be practically determined w
exceedingly narrow limits, as a good boiler must be constru
of plate ranging in thickness from $\frac{1}{4}$ to $\frac{3}{4}$ an inch, as anyt
ss than the former cannot be properly caulked, and any t
s greater than the latter is difficult to rivet without the ai
inery. A thickness of $\frac{3}{8}$ seems to have become the stan
s for all diameters of boilers intended to sustain a
is, perhaps, arises from the fact that boiler-ma
acquainted with the practical limit to the stre
because it has of late years been used more
theless, for steel, or some of the higher grad
less thickness will suffice for the same pr

r Plates.—As already stated, the materials now commonly r the shells of boilers are wrought-iron and steel. The ations for this material vary somewhat in different locali- t the following, being that of the Board of Trade, is much he material to have a tensile strength of from 54,000 to ounds per square inch, to show an elongation at the point re of not less than 18 per cent. in 10 inches, but should t 25 per cent., and, if annealed, not less than 20 per cent. inches wide to stand bending until the sides are parallel stance from each other not greater than three times the s of the plate. In some other requirements the contrac- area is specified instead of the elongation, and in some s both the elongation and contraction of area of cross are specified.

.—For stays the Board of Trade requirements are that ile strength shall lie between 54,000 and 60,000 pounds per nch, with an elongation of not less than 20 per cent. in 10 Steel which has been welded or worked in the fire should sed.

s.—If wrought iron is used, it should have a tensile strength ess than 45,000 pounds per square inch, and an elongation r cent. in 8 inches. If steel is used, the elongation should ess than 26 per cent. in 8 inches, and after tempering the should stand completely closing together. Experiments indicate that, so far as leakage is concerned, iron is pre- because it is not subject to the same degree of expansion traction as steel.

CHAPTER XI.

BOILERS: THEIR CARE AND MANAGEMENT

GENERAL INSTRUCTIONS.

Water Level.

On taking charge of an engine and boiler, first ascertai there is sufficient water in the boiler, and then trace out the p and connections between the engine, boiler, and pumps.

On first entering a boiler-room in the morning ascertain whe the water stands at the proper level or not.

Never fill a boiler with cold water while the shell, flues, tubes are hot, as the contraction induced by the tube in coo will have an injurious effect.

If the water should, from any unforeseen cause, become dang ously low, draw the fire, allow the boiler to cool down, and neit admit feed-water nor disturb the safety-valve.

In case the supply of water should be temporarily cut off, ow to the derangement of a pump, the bursting of a pipe, or other cause, stop the engine, cover the fire with fresh coal, shut the damper, so as to retain a sufficient quantity of water the boiler to start on.

In all cases where it is possible, regulate the feed-water so a send it into the boiler in a steady stream.

When fresh water is used in marine boilers it is best to salt water for a short time when first put into use, in order cover the parts with a thin coat of scale. This prevents them fr being injured by the action of fresh water.

Do not rely entirely on the glass water gauge, but try the ga *cocks. If they* do not agree, ascertain the cause and remedy *difficulty.*

The water gauges must be kept clean. They should be blown t frequently to prevent the passages from choking.

The water should not always be fed to the boiler by the same pparatus. It is always best to have two means of feeding the iler. Use them alternately to make sure that both are in work- g condition. Examine the check valve while the boiler is feed- g to satisfy yourself that it is working properly.

Firing.

Never start a fire under a boiler until you are satisfied there is ufficient quantity of water in it.

Before starting a fire under a boiler, place a small quantity of l on the grates, to prevent them from being warped by the tra heat of the new fire.

In starting a fresh fire under a boiler while it is cold, always ow it to burn gradually at first, in order to bring all the parts the boiler to a uniform temperature.

Fire slowly and evenly. If the draft is weak or the coal poor, n fires must be carried in order to supply the necessary amount air. Medium thick fires are more economical with good draft d fuel.

Keep the grate covered with fuel and do not allow any holes in fire, as the air passing through carries away heat, wasting fuel.

Do not clean the fires any oftener than is necessary.

The fires should not be disturbed while there is a bright light the ashpit from the glowing coals in the furnace.

If there are several furnaces, they should be fired one at a e, as the unconsumed carbon which always tends to pass out the stack when fresh coal is put on the fire, is ignited by the t from the other furnaces. Besides the supply of steam is more iform when the furnaces are fired alternately.

It is important that the fires should be fed frequently with a **e coal rather than** by heaping on a great deal at a time. By **nding to this** *the economy is much* greater and the supply of ***m more uniform.***

The best coal to use for steaming is that which is clean, b and free from slate and earthy matter. It is poor economy t cheap coal, as it requires constant cleaning of the fires and in grates.

Steam Pressure.

Never carry a higher pressure of steam than is necessary allow the water to rise above the second gauge-cock in the b when the engine is running.

Never open a steam-valve on a boiler under pressure qu for the purpose of allowing steam to escape into the atmosp or into a boiler containing a less pressure, as it is attended w certain amount of danger, and may possibly produce an e sion.

The steam gauge should stand at zero when the pressure If it does not, the pointer should be adjusted.

The safety valve should be ample in size, and it should be at least once a day to make sure that it acts freely.

When the safety valve is blowing off the steam gauge s show the pressure at which the valve has been set. If it doe find out which is wrong and correct the difficulty.

Cleaning and Blowing Off.

The heating surface should be kept clean, otherwise th of combustion will not be effective in raising steam. The should at first be examined frequently to ascertain how much and scale has accumulated, and they should be removed at lar intervals.

Clean the flues or tubes of the boilers at least once a wee never allow ashes or cinders to accumulate under the grates

Boilers under which a forced draught is used require cleaned oftener than when the draught is natural.

When preparing to clean boilers allow them to cool dow the water to remain in them until ready to commence clean

***If the feed* water** is muddy or salty blow off a portio *quently and* blow off the boiler entirely, at least once a we

ver neglect to blow out and clean boilers, even though sol- are used for the prevention and removal of scale.

ıen it becomes necessary to blow out a certain quantity of rater from a boiler every day, the hand should never be red from the cock or valve, as any diversion of a person's ion from it may allow too much to be blown out, and the to be ruined.

ver blow out a boiler under a head of steam, as the heat ining in the boiler will bake the scale and mud on the sheets lues, after which it will be impossible to soften it again.

amine the blow-off cock and see that no water is escaping it is supposed to be closed. The blow-off cock and check s should be examined every time the boiler is emptied.

Leaks.

aks should be repaired as soon as they are discovered.

a tube becomes leaky in the tube-sheet, it may be made by inserting a tapering ferule about $\frac{1}{16}$ of an inch larger than ıside diameter of the tube.

a tube splits, it may be plugged with either iron or wooden , whichever is most convenient. Iron is best for the end the furnace, while wood will answer for the smoke-box end.

e object of caulking is to bring together the seams of boilers, , or hulls of iron vessels after riveting, so that they may be tly steam- or water-tight. This is done by using a sharp round to a slight angle. The edge of the plates being first ed or planed to an angle of about 110°, the calking tool is ed to the lower edge of the chipped or planed angle, in order ve or upset the edge, thus bringing the plates together, and ring the joint to all appearances perfectly steam-tight, and to resist the internal pressure brought to bear upon this par- ır point. There are different methods of calking, but the ıve method has many points of preference over any other. rs *should never be calked* while under steam- or water- re, *however light, as the jarring* induced by the calking is liable to spring the seams and cause fresh leakage in other pa of the boiler.

Scale Formation and Corrosion.

The tendency in all boilers is toward the formation of a no conducting scale or incrustation on their heating surfaces, whi lie between the iron and the water. It not only causes an i creased consumption of coal, but allows the iron to become cry tallized and burned. The evil effects of the scale are due to th fact that it is a non-conductor of heat. Its conducting powe compared with that of iron, is as 1 to 35.5. Consequently, mor fuel is required to heat water in an incrusted boiler than in th same boiler if clean. A scale $\frac{1}{16}$ inch thick will require the ex penditure of 15 per cent. more fuel; this ratio increases as th scale thickens. Thus, when it is ¼ inch thick, 60 per cent. mor fuel is needed; ½ inch thick, 150 per cent., and so on; conse quently, to raise water in a boiler to any given temperature, th fire-surface of the boiler must be heated to a temperature corre sponding to the thickness of the scale.

To raise steam to a pressure of ninety pounds, the water mu be heated to about 320° Fah. In a clean boiler of ¼ inch iro this may be done by heating the external surface of the shell t about 325°. If ½ inch of scale intervenes between the shell a the water, such is its non-conducting power, that it will be nece sary to heat the fire-surface to about 700°, almost red heat. No the higher the temperature at which iron is kept, the more rapidl it oxidizes, and at any heat above 600° it very soon becomes gra ular and brittle, and is liable to bulge, crack, or otherwise gi way to the internal pressure. This condition predisposes the boil to explosions, and makes necessary expensive repairs. Again, it i readily seen that the presence of scale renders slower and mo difficult the raising, maintaining, and lowering of steam.

The minerals which constitute the basis of the scale whic forms in steam-boilers using fresh-water from wells, lakes, o rivers, are sulphate of lime, phosphate of lime, carbonate of lim magnesia, silica, and alumina, with small quantities of sesquioxide of iron, baryta, carbonic acid, organic matter, chlorine, sulphuric acid, potash, calcium, soda, phosphoric acid, magnesium, etc.

The principal ingredient in the scale which forms in marine boilers using sea water is sulphate of lime, but no very injurious ffect will take place in boilers if the degree of saltness is not llowed to exceed $\frac{4}{32}$. In fact, a thin coat of scale is beneficial, as it protects the iron from corrosion and internal grooving.

An analysis of sea water shows the relative quantities of the ngredients it contains:

Water	964.745
Chloride of Sodium	27.059
Chloride of Potassium	0.766
Chloride of Magnesium	3.666
Bromide of Magnesium	0.029
Sulphate of Magnesia	2.296
Sulphate of Lime	1.406
Carbonate of Lime	0.033

The methods for preventing the formation of scale in steam oilers are innumerable. In general it may be said that where e quantity of scale-forming ingredients is small, say 12 grains er gallon, the trouble may be obviated by the use of chemicals boiler compounds.

The composition of boiler compounds should be determined the nature of the feed water, and a compound that is very ective in one case may be worse than useless in another. r example, if the impurity in the water consists largely of sulate of lime, it may be prevented by adding the proper amount carbonate of soda and introducing it into the boiler regularly th the feed water; but if the scale-forming ingredient is silica alumina, say, the addition of carbonate of soda to the feed ater will be ineffectual. The formation of scale is prevented the use of boiler compounds only when their action is such as alter the *chemical composition of the* ingredients, so that instead *scale-forming salts they will become* soluble in hot water or such a nature that they will be precipitated in the form of powde or grains.

It is evident, therefore, that no boiler compound can be effectiv in preventing the formation of scale in all cases. In order to determine the kind of preparation to use in any particular case i is necessary to have a complete chemical analysis of the fee water. There are many boiler compounds some of which ar excellent for individual cases: but it may safely be assumed tha if any one preparation is guaranteed to prevent scale or incrustation, no matter what the nature of the feed-water may be, th user will be liable to severe disappointment if nothing worse.

The following substances may be used effectively to preven the formation of scale: Carbonate of soda, if the ingredient whic tends to produce scale is sulphate of lime, sodium phosphate fo the sulphates of lime and magnesium, milk of lime for the carbonates of lime and magnesium, caustic soda and soda ash for the carbonate and sulphate of calcium and the sulphate of magnesiu and tannate of soda for the suphate and carbonate of lime.

If the quantities of scale-forming ingredients are large, boil compounds are of but little use. In such cases the source of wat supply should be changed, or else the water should be purifi The use of a feed-water heater is sometimes sufficient, while a co denser used in connection with the engine always insures pu water. If the water is absolutely free from salts, or if it slightly acid, it should be neutralized by adding a small amou of lime. Rain water and condensed steam should be treated this way, otherwise they will corrode the iron.

To remove hard scale from boilers it has been found well add ¼ pound of caustic soda per horse-power and steam for a fe hours. If this is done just before cleaning, the removal of sca will be greatly facilitated.

The term corrosion means wasting, pitting, or grooving of th ial, and is generally referred to under two heads, namel and external.

corrosion presents itself in different forms, and is auses, but principally to the minerals and acids con- the feed water with which steam-boilers are supplied. **al corrosion** is said to be due to the galvanic action of the in the fuel and the gases in the atmosphere, and both causes ately associated with combustion, or stimulated by it; as and minerals which are in solution in the water, and lib- the heat, attack the boiler internally, while the sulphur liberated by the combustion of coal has a strong affinity ron of which boilers are constructed, and attacks it ex-

ion in marine boilers is caused chiefly by the action of r and air while the boiler is under steam, and by the moisture and air when it is standing idle. Numerous ave been employed to overcome this difficulty, the most of which are the formation of a thin layer of scale by for a short time with sea water, painting the interior tland cement, or the use of metallic zinc suspended in the d steam spaces. The two former methods reduce the of the heating surface somewhat, but aid materially in g the life of the boiler. The action of the zinc is galvanic, e excellent results have been produced by its use in some as been found in others to produce a hard and tenacious

Foaming.

ng in marine-boilers using jet-condensers is generally changing the water from salt to fresh, or *vice versâ*, and vident by the boiling up of the water in the glass gauge. ming arises from this cause, the water in the boiler should ed as soon as possible, which can be done by putting on a d, and blowing out continuously, or at short intervals; en become necessary to throttle down the engine, cut off even stop, in order to ascertain the level of the water in s.

t *foaming can be checked* by opening the furnace-door, *damper, and covering* the fire with fresh coal; but this means of relief should be used as little as possible, because it has tendency to injure the boiler, owing to the sudden contraction of th parts most exposed to the fire. All the phenomena connected wit foaming have not yet been satisfactorily explained; but, fro whatever cause it may arise, it is always attended with a certa amount of danger. *Foaming* is sometimes confounded with *pri ing*, but they arise from different causes, and are productive of dif ferent results. *Foaming* is always made manifest by the viole agitation, the rising and falling of the water in the gauge, an the muddy appearance of the water.

Foaming is induced in stationary boilers by a filthy conditio particularly in those to which the feed-water is supplied throug open heaters, in consequence of the oil or tallow employed f lubricating the cylinder being carried over with the exhau steam. The water in locomotive-boilers foams on some parts the road, while on other sections this phenomenon never ma fests itself, which may be attributed to the presence of alkali saline matter in the water with which the boilers are supplied certain parts of the road. Foaming is induced in all boilers b the want of proper proportion between the water-space, heatin surface, and steam-room of the boiler, and also from the absen of sufficient steam-room in the boiler to supply the cylinder.

Priming.

The term Priming is understood by engineers to mean th passage of water from the boiler to the steam-cylinder in th shape of spray instead of vapor. It may go on unseen, but it generally made manifest by the white appearance of the stea as it issues from the exhaust-pipe as moist steam, which has a whi appearance and descends in the shape of mist, while dry steam h a bluish color and floats away in the atmosphere. Priming al makes itself known by a clicking in the cylinder, which is caus by the piston striking the water against the cylinder head at eac *end of the stroke.*

Priming is generally induced by a want of sufficient steam-ro

boiler, the water being carried too high, or the steam-pipe
too small for the cylinder, which would cause the steam in
oiler to rush out so rapidly that, every time the valve
d, it would induce a disturbance, and cause the water to rush
nto the cylinder with the steam.

Steam-Boiler Explosions.

principal causes of explosions,[*] in fact, the only causes,
ficiency of strength in the shell or other parts of the boilers,
essure and *over-heating*. Deficiency of strength in steam-
may be due to original defects, bad workmanship, deterio-
from use or mismanagement. Deficiency of strength aris-
m bad workmanship is the most difficult to discover, and
frequently escapes the closest scrutiny, more particularly in
e of flue, tubular, and locomotive boilers.

r-pressure may be caused by the safety-valve being over-
ed; by its sticking on its seat; by the inadequate size of
nmunication between the boiler and valve, or by an incor-
d worthless steam gauge. Overheating may be produced
here is a disproportion between the grate- and heating- sur-
or where the heat from a large grate is concentrated on a
space. Under such circumstances, the heat is delivered with
ntensity as to lift the water from the surface of the iron,
y exposing it to the direct action of the fire.

losions occurring from excessive firing are in all cases the
of avarice, ignorance, or a want of skill in the care and
ement of the steam-boiler. Overheating may be caused
accumulation of hard, solid incrustation adhering to the
nost exposed to the direct action of the fire, or it may be
insufficiency of water, resulting from leakage of the valve
-cock, a failure in the supply-pipe, or a neglect to turn it
he proper time or in sufficient quantity.

eam-boiler may be well designed, of good material, and of first-class workmanship, and yet in a few months, after being p under steam, it may explode with terrible effect. On examini into the cause of the explosion, it may turn out that the wat used made a heavy deposit; that the boiler had not been clea since it was put into use; that the fires had been fiercely urg and the water driven from the surface of the iron; as a resul the life had been entirely burned out of the sheets over and arou the fire, thereby weakening the boiler, and putting it in a da gerous condition. That the sudden heating or cooling, and oxid tion of the boiler, induce great deterioration of strength h been proved by experience. Defects in the material, as bliste lamination arising from inferior material, or want of care in th manufacture, are other sources of weakness in steam-boilers.

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[*] *See Roper's "Use and Abuse* of the Steam-Boiler."

Upward of 300 boiler explosions occur annually in the Unite States, incurring the loss of over 300 lives and 450 injuries of more or less serious character.

Technical Terms used in Connection with Boilers an their Adjuncts.

Air-casing.—An arrangement attached to fire- and smoke-bo doors for the purpose of preventing radiation of heat.

Ash-pit.—The space below the grate, where the ashes accu mulate.

Blast-pipe.—A small pipe used to blow steam into the funnel of locomotive and marine-boilers for the purpose of exciting th draught in the furnace.

Blow-off cocks.—Cocks used for blowing the water out o steam-boilers.

Check-valve.—A valve used to retain the water in steam boilers, and relieve the feed apparatus from the pressure.

Check-chamber.—The chamber in which the check-valv operates.

Connecting-pipes.— The pipes which connect check-valves with am-boilers.

Crown-sheet. —That part of fire-box boilers (locomotive or arine) directly over the fire.

Crown-bars.—Bars placed on the upper side of crown-sheets, the water-space, for the purpose of strengthening them.

Curvilinear Seams.—The curvilinear seams of a boiler are ose around the circumference.

Crown-braces.—Braces attached to the crown-bars, and to the ells and domes of boilers, for the purpose of resisting the pressre exerted on the flat surfaces of crown-sheets.

Dashers.—Iron plates which are sometimes attached to the inide of steam-boilers to prevent the cold water, as it enters, from riking the tubes.

Dead-plate.—The solid iron plate which fills the space between he end of the grate-bars and the fire-door of boiler-furnaces.

Deflector.—An arrangement employed, in the furnaces of locootives and marine-boilers, for the purpose of mixing the air and ases arising from the combustion of the fuel, and causing them o ignite.

Diaphragm-plate.—A perforated plate, used in the steam-domes f locomotives and marine-boilers, to prevent the water from being arried over into the cylinder with the steam.

Dome.—An elevated chamber on the top of steam-boilers, from hich the steam is generally taken for the cylinders.

Dome-stays.—Stays employed, in the domes of locomotives and arine-boilers, for the purpose of strengthening them.

Dry Pipe.—*A perforated pipe* placed in the steam space, from which the steam is taken from the boiler—frequently used in p of domes.

Flue.—Any portion of a boiler through which the product combustion from the furnace pass before entering the stack.

Forced Draught.—A supply of air to the furnace by method other than the natural draught produced by the chimn

Grate Surface.—The aggregate area of the grate, including bars and the spaces between the same. It is usually measured square feet.

Gusset Stays.—Triangular plates of iron used for staying flat ends to the cylindrical shell of a boiler.

Heating Surface.—All that portion of the surface of a boi internal and external, that is touched by steam or water on one side and by the combustion gases on the other.

Knees.—Brackets riveted to the sides of steam-boilers, for purpose of sustaining them on their supports.

Longitudinal Seams.—The seams which are parallel to length of a boiler are called the longitudinal seams.

Shell.—The outside steel or wrought-iron casing of a boi (formerly made of cast-iron).

Spanner-guard.—An arrangement employed to prevent co and valves, connected with marine engines and boilers, fr being opened or closed by accident.

Scum-cocks.—Cocks employed to blow off extraneous s stances from the surface of the water in steam boilers.

Spectacles.—Pieces of iron, with concave sides, employed *braces between* the tubes of marine boilers, generally for the *nose of stopping* leaks.

Steam-space.—That part of a boiler occupied by the steam. n practice it is about one-fourth of the cubic contents of the oiler.

Stay-tubes.—Tubes used for bracing marine boilers. They are enerally made of thicker material than either the ordinary fire- r water-tubes.

Tube-sheets.—The sheets into which the tubes are inserted at ach end of the boiler.

Waist.—A term applied to the cylindrical part of locomotive- r marine-boilers.

Water-space.—That part of a steam-boiler which is occupied y the water. It is generally about three-fourths of the cubic ntents of the boiler.

Technical Terms applied to Firing.

Start Fires.—This term is understood to mean starting fresh res in furnaces with shavings, wood, coal, etc.

Bank Fires.—This term is understood to mean covering the res down with a thick body of coal at night, or when the engine s to be stopped for an indefinite period.

Slice Fires.—This means to push back the fire to the bridge-ll, and then draw out the cinders, after which the fire is drawn rward, distributed over the grates, and fresh fuel supplied. The rms slice and clean fires have the same meaning.

Draw Fires.—This term is understood to mean to draw the ntire fire from the furnace for the purpose of allowing the furnace o cool for stoppage or repairs, as the case may be.

QUESTIONS.

THE ANSWERS TO WHICH MAY BE FOUND IN THE TEXT.

How were the first steam boilers constructed?

What were the reasons for abandoning the plain cylindr boiler?

Describe and make sketches of the Cornish, Lancashire, Galloway boilers.

What are the advantages of Galloway tubes?

Why are furnaces of boilers made corrugated?

What is meant by a tubular boiler?

What is the difference between a tubular boiler and a ret tubular boiler? Make a rough sketch of each.

Make a sketch showing the method of setting a tubular bo in brick-work.

What is the course of the combustion gases in a return tub boiler?

What is the difference between an internally and an extern fired boiler? Make sketches showing the difference in the sett

What different methods are employed in tubular boilers taking off the steam?

What advantages have tubular boilers over other types?

Describe the Babcock and Wilcox type of steam boiler.

What are some other water-tube boilers?

Describe the Bellpaire fire-box boiler.

What advantages are claimed for water-tube over fire-t boilers? Which of the two is the safer? Which is the chea to build?

Why is the fire-tube or tubular type of boiler preferabl some cases to the water-tube type?

What are the characteristics of marine boilers?

Why are the boilers used for marine purposes built differen from those used on land?

Make a sketch of a modern marine boiler, showing the shell, *naces, tubes,* and method of staying. Indicate, by arrow *course of the* gases.

How many furnaces are used in marine boilers of different meters?

Why do the furnaces in marine boilers have independent com- stion chambers?

What conditions must be taken into consideration in designing omotive boilers?

What are the principal features wherein locomotive boilers dif- r from stationary and marine boilers?

How is the draught produced in locomotive boilers?

What material is used in the construction of the fire-boxes of omotive boilers? Why are they not made of the same mate- throughout?

Is the locomotive type of boiler used for any other purpose? at would be the object of using it for any other purpose?

Define horse-power of boilers. What is the Centennial rating?

ow should boilers be rated?

What conditions affect the quantity of steam that can be gene- d in a boiler?

What amounts of water can be evaporated in fire-tube and er-tube boilers under good conditions? How much is usually porated in practice?

What percentage of the fuel is utilized in actually making m? What becomes of the balance?

What considerations determine the surface of the grate? Is it, eneral, an advantage to have a large grate surface?

a 50-horse-power boiler, having a grate surface of four- square feet, how much coal would be consumed per hour, quality of the coal and the condition of the boiler being good?

the above boiler what would be the consumption of coal per e-power per hour? How much water per pound of coal ld be evaporated from and at 212°?

hat is the average ratio of heating surface to grate surface in nary boilers using anthracite coal? What is it where bitu- s coal is used?

at is the heating surface in the tubes of a marine boiler *g 216 two-inch tubes?*

What is the total heating surface of an externally fired tub boiler 6 feet in diameter, 10 feet long, having 100 three-i tubes?

What pressure will burst a cast-iron cylindrical boiler inches in diameter, the tensile strength of the material be 18,000 pounds, and its thickness 1 inch?

What pressure can be safely carried in a cylindrical boiler single-riveted joints, the diameter being 5 feet, thickness of s ⅜ inch, tensile strength 55,000 pounds, and factor of safety 4?

What should be the thickness of the shell of a stationary boi 6 feet in diameter, with double-riveted joints, to safely carr pressure of 200 pounds per square inch, using a factor of saf of 4?

What pressure can be carried with safety on a boiler flue 2 in diameter, 10 feet long, and ⅜ inch thick?

What different methods are used for staying boilers?

What materials are mostly used in the construction of ste boilers?

What qualities are most essential in a good boiler materi What are the most common defects?

What are the characteristics of boiler iron when broken?

What material is preferable for tubes? Why?

Explain the meaning of the technical terms applied to the d ferent adjuncts of steam boilers.

What course should an engineer or fireman pursue when f entering the boiler-room in the morning?

What precaution should be taken before starting a fire und boiler?

What course should an engineer adopt on taking charge of engine and boiler for the first time?

How should the fire be regulated when first started unde boiler?

Under what conditions should a boiler be blown out?

What should be the condition of a boiler when it is to be fi *with cold water?*

hat course should be adopted with boilers before cleaning?

w should boilers be treated when a *forced draught* is used?

w should the pressure in a boiler be regulated?

w should the kindling material be placed on the grate pre-
ory to starting a fire?

w often should steam-boilers be cleaned?

ould the cleaning of boilers be neglected, when solvents are
for the prevention and removal of scale?

hat precautions should be taken before new boilers are put
ervice?

w often should the flues or tubes of boilers be cleaned?

hat course should be adopted in case the water in a boiler
nes dangerously low?

hat course should be pursued in case the water-supply be-
s interrupted for any length of time?

hat precaution should an engineer take in case it becomes
sary to blow out a certain quantity of water every day?

w should the supply of feed-water be regulated?

hat advantages are gained by filling marine boilers with salt-
for the first time?

hat is the meaning of the term "salting" when applied to
e-boilers?

at parts of any class of steam-boilers are most likely to suf-
m the effects of heat?

at is the most practical method to adopt in case a boiler
hould become leaky?

at course should an engineer or fireman adopt in case a
ecomes split?

PART IV.

STEAM BOILER FITTINGS AND APPLIANCE

CHAPTER XII.

VALVES, GAUGES, ETC.

Safety Valves.—It frequently happens in steam boilers t through causes over which the fireman has no control, but n frequently through negligence on his part, the steam pres rises above that which the boiler is designed to carry. O ously, when this is the case there would be great danger of str ing the boiler or even of its entire destruction, if it were not vided with some device for relieving the excess of press Devices used for this purpose are called safety valves, and t consist essentially of a combination of a valve with weight springs and levers, so arranged that when the pressure in boiler exceeds that which it is intended to carry, the valve and allows the pressure to be relieved.

The lift of safety-valves, like all other puppet-valves, decre as the pressure increases; but this seeming irregularity ma explained as follows: a cubic foot of water generated into st at one pound pressure per square inch above the atmosphere have a volume of about 1600 cubic feet. Steam at this pres will flow into the atmosphere with a velocity of 482 feet per ond. Now, suppose the steam was generated in five minutes, c 300 seconds, and the area of an orifice to permit its escape as as it is generated be required, 1600 divided by 482 × 300 will the area of the orifice, 1⅗ square inches. If the same qua ter be generated into steam, at a pressure of 50 pounds e the atmosphere, it will possess a volume of 440 cubic feet, will flow into the atmosphere with a velocity of 1791 feet per d. The area of an orifice, to allow this steam to escape in ame time as in the first case, may be found by dividing 440 791 × 300; the result will be $\frac{3}{25}$ square inches, or nearly $\frac{1}{8}$ of uare inch, the area required. It is evident from this that a less lift of the same valve will suffice to discharge the same ht of steam under a high pressure than under a low one, bee the steam, under a high pressure, not only possesses a red volume, but a greatly increased velocity; it is also obvious a safety-valve, to discharge steam as fast as the boiler can rate it, should be proportioned for the lowest pressure.

here does not appear to be any recognized rule among boiler ers for proportioning safety-valves, since, while one allows one of area of safety-valve to every 66 square feet of heating-ce, another gives 1 inch area of safety-valve to every 4 horse-er, while a third allows 1 inch area of safety-valve to $1\frac{3}{4}$ square of grate-surface. This last proportion has been proved by rience to be capable of admitting of a free escape of steam, out allowing any greater increase of pressure than that for h the valve is loaded, providing that all the parts are in good king order. It is obvious, that no valve can act without a t increase of pressure, as, in order to lift at all, the internal sure must exceed that of the load. Doubtless, most safety-es are larger than is actually required, and but few boiler osions occur from want of safety-valve area. The most prob-causes of accidents arising from safety-valves are that they either overloaded or out of order. A badly proportioned y-valve, whether too large or too small, is objectionable, and ways attended with a certain amount of danger.

fety valves may be divided into three general classes, accord-o the manner in which they are loaded.

he simplest form *of safety valve* is that in which an ordinary

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afety valves may be divided into three general classes, accord-
to the manner in which they are loaded.

he simplest form *of safety valve* is that in which an ordinary which the position of this plug *H* will be clear. It is pr with a check nut to hold it in position after the desired p been obtained. The lock-up arrangement is also clearly sh

Ashton Lock-up Pop Safety Valve.

this cut, and it will be seen that the padlock must be re before the regulating screw can be reached. The trip le movable, and may be readily changed to stand in any d position.

Rules.

le *for finding the weight necessary to put on a safety-valve the area of valve, pressure, etc., are known.*—Multipl f valve by the pressure in pounds per square inch; product by the distance of the valve from the ful multiply the weight of the lever by one-half its length (or its entre of gravity); then multiply the weight of valve and stem y their distance from the fulcrum; add these last two products ogether; subtract their sum from the first product, and divide he remainder by the length of the lever; the quotient will be the weight required.

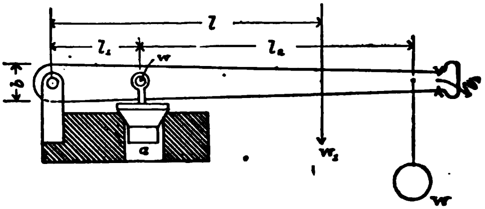
Rule *for finding the pressure per square inch when the area of valve, weight of ball, etc., are known.*—Multiply the weight of ball y the length of lever, and multiply the weight of lever by one-half its length (or the distance from the fulcrum to its centre of gravity); then multiply the weight of valve and stem by the distance from fulcrum. Add these three products together. This um divided by the product of the area of the valve, and its distance from the fulcrum, will give the pressure in pounds per quare inch.

Rule *for finding the distance from the fulcrum at which the weight hould be placed for a given blowing-off pressure.*—Multiply the area of the valve in square inches by the steam pressure per square nch and subtract the weight of the valve and stem in pounds. Muliply the difference by the distance from the valve to the fulcrum n inches, and to this product add the product of the weight of he lever by the distance of its centre of gravity from the fulcrum. This sum, divided by the weight of the ball in pounds, will give the required distance in inches.

Rule *for finding the distance of the centre of gravity of taper levers from the fulcrum.*—To the width of the small end of the lever add ne-third of the difference between the large and the small end of he lever. Multiply the sum by the length of the lever and divide he product by the sum of the large and the small end of the ever, all in inches. The quotient will be the required distance in nches.

All of the preceding rules may be expressed by simple formulæ, as follows:

Let the diagram on *page 222* represent the lever safety valve *shown on page 218 d, and let*



W = weight of ball in pounds.
w = " valve and stem in pounds.
w_1 = " lever in pounds.
l_1 = distance from fulcrum to valve in inches.
l_2 = " " valve to ball in inches.
l = " " fulcrum to centre of gravity of lever in in
p = steam pressure in pounds per square inch.
a = area of valve in square inches.
b = width of large end of lever in inches.
b_1 = " small " " "
L = total length of lever.

Then:

$$p\,a\,l_1 = w\,l_1 + w_1\,l + W(l_1 + l_2)$$

$$W = \frac{p\,a\,l_1 - [w\,l_1 + w_1\,l]}{l_1 + l_2}$$

$$p = \frac{w\,l_1 + w_1\,l + W(l_1 + l_2)}{a\,l_1}$$

$$l_1 + l_2 = \frac{p\,a\,l_1 - w\,l_1 - w_1\,l}{W}$$

$$l = \frac{b + 2b_1}{b + b_1} \times \frac{L}{3}$$

Areas of Safety Valves.

As has been stated above, there is no general rule for d mining the areas of safety valves. The following rule is one nended by a committee of the Franklin Institute, appointed in 7 for the purpose of investigating the matter.

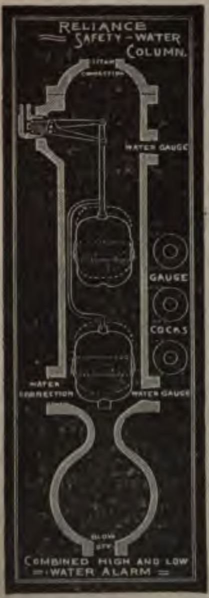
ule.—Multiply the grate area in square feet by 22.5 and ide the product by the sum of the steam pressure in pounds square inch and the constant number 8.62. The quotient will the area of the safety valve in square inches.

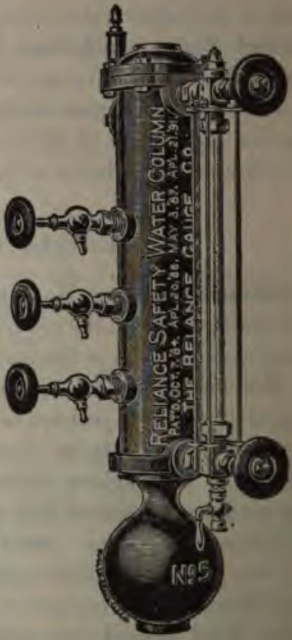
he United States regulations for steam vessels require that er safety valves shall have an area of not less than one square h to two square feet of grate surface, and the seats of the valves st have an inclination of 45° to the centre line of their axes. is rule is frequently adhered to for stationary boilers also.

Safety Water Columns.

afety Water Columns.—Next to keeping the steam pressure hin the limits of safety, the most important point to be observed operating steam boilers is the maintenance of the proper water el. If the water level is too low, there is danger of burning tubes and plates and perhaps of wrecking the boiler; if it is high, water is liable to be carried along with the steam and se damage in the engines, while a constant variation in the ter level produces a waste of fuel and unsteady pressure, and im- irs the life of the boiler. Safety water columns have been ised for the purpose of insuring owners of steam boilers against idents of this kind. They are so arranged that any variation the water level beyond reasonable limits will be loudly pro- imed by means of a suitable steam whistle. The accompanying s illustrate the Reliance Safety Water Column. The apparatus intended to replace both the gauge cocks and glass water ge ordinarily used, and contains in addition the mechanism erred to above for giving an alarm when the deviation of the ter level from the normal becomes too great. It will be seen m the sectional view of the apparatus that the outside casing tains two floats *suspended by links* from two bell crank levers *ich are attached to the whistle.* So long as the water line is

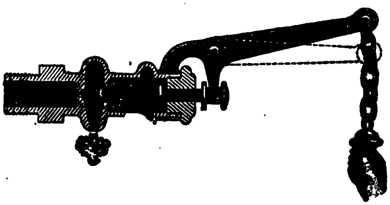
above the centre of the lower gauge cock and below the ce
the upper gauge cock, the bottom float presses upward by
of its buoyancy, while the top float presses downward by
of its weight and the two valves to the whistle remain




RELIANCE SAFETY WATER COLUMN
PAT'D OCT. 7, '84. APL. 20, '86. MAY 3, '87. APL. 21, '91.
THE RELIANCE GAUGE CO.
No 5

When, however, the water line passes the centres of eit
upper or lower gauge cocks, the reverse of the above tak
and the valve is opened, giving the desired alarm. T
shaped chamber at the bottom is for the purpose of collec
sediment and is provided with a blow-off opening. The
are tapped for standard fittings, so that any kind of wate
or gauge cocks may be used. The annexed cut shows
form of gauge cock which may be used where the water
so high that the cocks could not be conveniently reached

ant. It differs from the usual type in this particular, that l of pulling down the to open the cock, the is lifted, and when it is held against the erely by the weight ball. This arrange- has the advantage he seat, not being next to the boiler, s the cutting effect of the sediment.



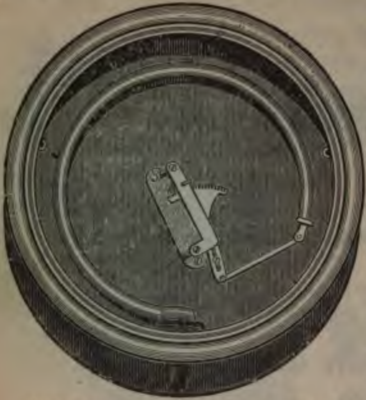
Reliance Leakless Gauge Cock.

Steam Pressure Gauges.

ut the year 1849 Eugene Bourdon, of France, discovered ie free end or ends of a flattened or elliptical metallic tube, ing sufficient elasticity for use as a spring, would move pressure was exerted in it through the medium of a applied externally or internally; that the motion was ct proportion to the pressure applied; and that when the re was removed they assume their former n. From this circum- he conceived the idea ew pressure gauge, in the bent tube should main spring or means tion. But, though it enerally conceded at ime that the hollow ring gauge, as invent- Bourdon, excelled in y and sensitiveness evious *mechanical ar- ıent employed for that*

Exterior View of Crosby's Steam Gauge.

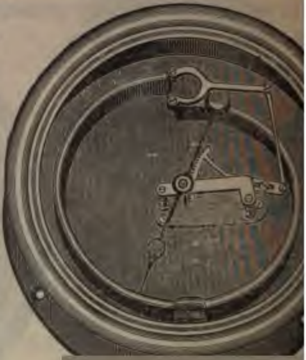
purpose, nevertheless, it was demonstrated by experience tha



Interior View of the Original Bourdon Steam Gauge.

a device, owing to its
liar construction, was no
adapted for all the purpos
which pressure gauges ar
ployed, as, in consequen
being held only at one e
would vibrate from a s
shock or slight change of
ure, thus causing the poin
oscillate on the dial-plat
ducing friction and wear
rendering the indicatio
the gauge uncertain and
sive. Besides, the dip of
a spring caused it to ret
portion of the water condensed in it, thus rendering it lia
burst in cold weather, to be strained by freezing, and lose its te

To overcome these defects, numerous devices have
suggested and tried, but they almost invariably embodied the same defects as those above mentioned, and were subject to the same errors, the gravest of which arose from the straightening or setting of the springs. Steam users are more indebted to George H. Crosby for remedying the foregoing defects in pressure gauges, and for the production of a perfectly reliable steam gauge, than to any one previous to his time, as he dis-
covered, by observation and ex-
riment, that only the horizontal motion of the free ends



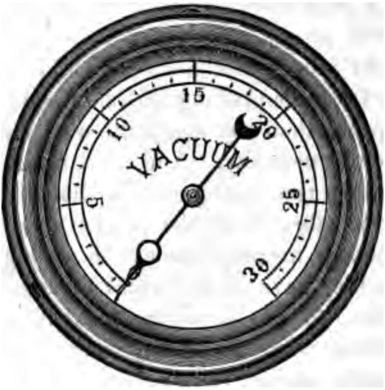
Interior View of Crosb
Steam Gauge.

ngs or tubes, while under varying pressure, had been used tofore, and that they had a perpendicular or upward action, ell, when the springs were of proper length and shape, and ; by uniting these motions by proper mechanism, it could all ransmitted to the pointer. In accomplishing this, he discov- l that a firmer and stiffer spring than any heretofore used for same pressure was an absolute necessity. And as a result, pressure over that indicated by the pointer on the dial will ct their original elasticity, and vibration of the pointer under ying pressures is obviated; besides, in consequence of the spring ig held at the lowest points, they have no dip, which arrange- it admits of the water returning to the siphon, thus preventing zing. Thus it would seem that, while the Crosby gauges em- ce all the desirable points in the original Bourdon gauge, they embody many others which have been demonstrated by expe- ice to be absolute necessities in the construction of an accurate, able, and serviceable steam gauge.

elf-Testing Steam Gauges.—This class of gauges is of great ortance, convenience, and utility, as the engineer in charge can ays ascertain whether his gauge is correct or not by observing following instructions: off all pressure that may on the gauge, after which pointer will fall to zero; unscrew the plug on the hand side, which uncov- the hook. To this hook the first weight by the dle. This is marked by ertain number, and the nter should travel at once he corresponding number he dial, if correct at this it. But if *the pointer ds below or above this*

Crosby's Self-Testing Steam Gauge.

number, it will indicate just how much the gauge is "out," an which direction. Procee adding the next higher n bered weight, and continu before.

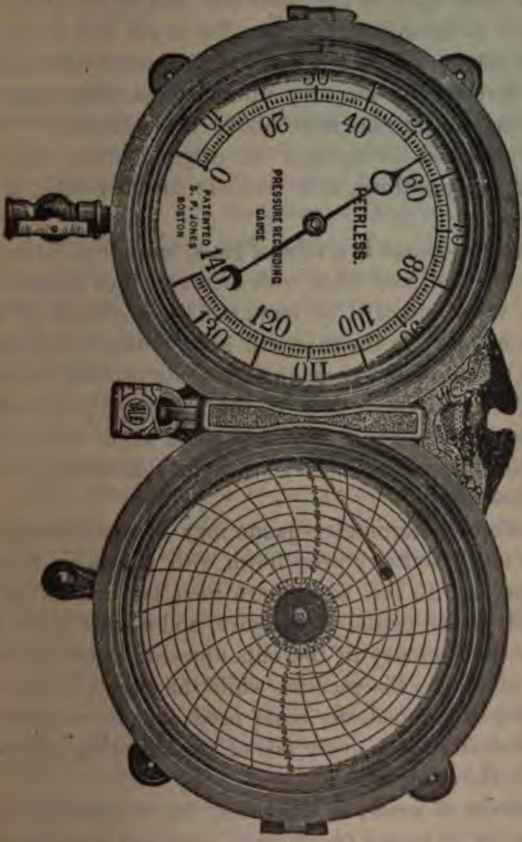


Crosby's Vacuum Gauge.

Vacuum Gauges.—The ditions under which vac gauges act are the revers steam gauges, as, in the v um gauge, the interior of tube is influenced by the v um, while its exterior is posed to the action of th mosphere. The principle covered by Bourdon is app in most of the gauges now used, as it has been found applicab the various devices which are used in measuring pressure vacuum.

Recording pressure gauges, though a comparatively re addition to the list of appliances which are to be found in boiler room, are now used in every well-equipped plant. first of these to be placed on the market was the Bristol Rec ing Gauge, and the other makes are largely modifications of type. The recording gauge consists essentially of a combina of a clock mechanism with an ordinary steam gauge. The consists of a removable paper which is arranged to make complete revolution in twenty-four hours. The circles on dial indicate the pressure, while the sinuous lines indicate hour. By the combined motion of the pointer, which is actu by the steam pressure, and the dial, which is actuated by clock-work, a record is made of the pressure which has been ried in the boiler. The end of the pointer is filled with ink to make an indelible record. The cut on page 229 shows o *these gauges* mounted with an ordinary gauge, which makes a *and useful* appliance for the boiler room.

siphon-gauge is a bent tube, inverted, and partially filled mercury. The orifice of the short leg is connected with the er, and the long leg is open to the atmosphere. The steam sing upon the mercury in the short leg with greater force n the weight of the atmosphere, causes the mercury in the other to rise, and indicates *the excess* of pressure above that of the *osphere. To the amount* shown by the gauge must be added



the pressure of the atmosphere. Thus, if a siphon-gaug 15 pounds pressure, the boiler-pressure is 30 pounds.

A mercurial gauge for high-pressure steam engines of a glass tube open at the lower end, and closed at the t taining air in its ordinary state. Its lower end is place cistern of mercury. When the cock is opened the steam through, forcing the mercury up the glass tube, thereb pressing the air in the tube above the mercury. Wh air is compressed to one-half its original space, the p is doubled; to one-third, it is trebled; to one-fourth, it is quadrupled, etc.

A barometer-gauge is a tube of glass, more than 30 inche closed at one end, and filled with mercury, then inverted the lower open end will be immersed in a cistern of m when the mercury in the tube will sink, rising in the basi [illegible] its weight balances the pressure of the atmosphere, which [illegible] to force the mercury up the tube [illegible] will be found to stand about 30 inches [illegible] varying slightly, according to th [illegible]

The scale of a barometer-gauge may be explained as [illegible] press down with the same force [illegible] per square inch, two inches of [illegible] pressure, and a scale of [illegible] upwards must be fix [illegible] when the engine is work [illegible] need only be marked [illegible] two denoting one po [illegible]

The [illegible] estimating the vacuum [illegible] That the pressure [illegible] is liable to change [illegible] marked, on the supposi [illegible] because it is [illegible] Therefore a fixed scale erroneous, on account of the sinking of the mercury in the cup as it rises in the tube.

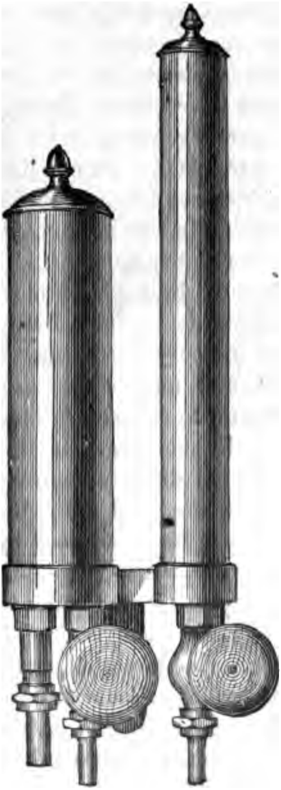
The first source of error may be corrected by observing the actual height of a weather barometer, and subtracting it from the height as shown by the gauge. This will be correct, if a tube of a standard diameter is used. This error may be corrected by a short gauge, similar to what a weather barometer would be if it were enclosed in a space, communicating with the condenser. In that event, before a vacuum is created, the mercury would stand as high in the glass tube as in the weather barometer. On creating a vacuum, thus taking off the pressure from the mercury in the cistern, the mercury would fall in the tube. In this instrument, the less the height of the mercury the better the vacuum.

The second source of error may be obviated by having a movable instead of a fixed scale, so that its lower end might always be kept in contact with the surface of the mercury in the cup.

A siphon-gauge, such as has been spoken of, may be used as a vacuum-gauge. When so used, it is necessary to connect the long leg with the condenser, placing a stick in the short leg. In this case the scale would require to be graduated directly contrary to that for steam. The state of the atmosphere will affect the gauge. The pressure in the steam-boiler may be ascertained by the temperature, by the safety-valve, or by the steam-gauge, but it is not customary to measure the temperature in the boiler to ascertain the pressure. The scale of all pressure gauges should, from time to time, be compared with that of a standard gauge, and any error that may exist in the caliberation should at once be remedied. Similarly the blowing-off pressure of the safety valve should be tested, and care be taken to see that the valve lifts at the right pressure as shown by the gauge. The pressure gauge and the safety-valve are perhaps the two most important accessories of a steam boiler, as on these depend the safety of the entire plant. Hence, those in charge cannot be too careful to see that they are always *in proper working* order.

The Salinometer.*

A Salinometer is a form of hydrometer used to determin quantity of salt contained in the water of marine boilers, ar



The Salinometer.

which the amount of water nece to be blown out, to keep the wat the boilers at a certain density, m ascertained. It is a graduated tube, and floats in the water at a l proportional to its density or sal It is marked 0 for fresh water; sea-water that contains 1 lb. of s 32 lbs. of water; $\frac{2}{32}$ when it co 2 lbs. of salt to 32 lbs. of water, a on. Each division is subdivide four parts, showing halves and qu It is graduated for a temperatu 200° Fah. A uniform standa temperature is necessary, since must be taken from the pressure boiler, in order that it may assu regular temperature under the pr of the atmosphere, because stea different pressures has different peratures, and a difference in ten ture will alter the indications hydrometer.

The amount of salt in the wa a boiler may be ascertained by o ing the degree of the boiling-poi means of a thermometer. To d a sufficient quantity of the water in the boiler should be off in a long copper vessel, and brought to the boiling-point. *immerse the thermometer.* For every pound of salt contai *32 lbs. of water,* the temperature rises one degree. Thus, r contains $\frac{1}{32}$ of salt, it will boil at 213°; if $\frac{2}{32}$, at 214°; if $\frac{3}{32}$, 15·5°, and $\frac{4}{32}$, at 216·6°.

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* See page 237.

lt-water, at the usual density, contains $\frac{1}{32}$ of its weight of salt; equently, if one pound of salt enters the boiler with every 32 lbs. ater, and 16 lbs. of that water be evaporated, the one pound of remains in the proportion of 1 : 16. Again, if ½ of the 16 lbs. of r remains to be evaporated, the one pound remains in the 8 lbs. ater. Now, if these 8 lbs. of water were blown out of the boiler, alt would go with it; and so long as that proportion is carried out, aturation cannot exceed $\frac{4}{32}$; from which it is clear that, to keep r at $\frac{4}{32}$, one-fourth must be blown out; one-third at $\frac{3}{32}$, and at e-half of the water used for feed must be blown out.

he errors in the hydrometer may be corrected in the following ner: Every 10° difference in temperature will vary the indi- ns ⅛ of $\frac{1}{32}$, 200° Fah. being the standard. Then, if the water)° over 200° Fah., it will show ⅛ of $\frac{1}{32}$ less than its true density; if 10° below 200° Fah., it will indicate ⅛ of $\frac{1}{32}$ more. Moreover, e grade be 200° Fah., the thermometer shows 210°, and the hy- eter indicates a density of $\frac{2}{32}$, the true density will be 2⅛; if the temperature be 190°, it will be 1⅞.

Salinometer may be constructed by taking a long glass tube, inserting in it sufficient shot to sink it in fresh water, marking oint at which the water stands in the tube. Then immerse tube in water containing $\frac{1}{32}$ part of salt, when the point at h the water stands will be the sea-water mark. Similarly erse in water containing $\frac{2}{32}$, $\frac{3}{32}$, etc., up to $\frac{12}{32}$ of its weight lt, marking off the respective points at which the water stands. sfer these marks to a scale, and paste it inside the bottle in tly the same position as the marks on the bottle, and the result good salt-gauge. The temperature must always be the same hen the hydrometer was graduated.

ow to use a Salinometer.—Draw off some water from the rs, and when the ebullition has ceased, try its temperature with ermometer. *If the temperature* exceeds that marked on the *ometer; let it cool till it reaches* that degree; and if the temperature is less than that marked on the salinometer, it must raised till it reaches that degree. Then immerse the salinomet in the water and let it float; if the level of the water is at $\frac{2}{32}$ less, there is no occasion for blowing off; but if it exceeds $\frac{2}{32}$, th water must be changed. The degrees of temperature usuall marked on the salinometer are 190°, 200°, 210°. Before using th salinometer, it should be wet all over with water.

TABLE

SHOWING THE PROPORTION OF SALT IN THE WATER OF DIFFERENT SEA

	PARTS IN 1000.		PARTS IN 1000
Baltic Sea..................	6·60 = $\frac{1}{152}$	Mediterranean Sea.....	39·40 = $\frac{1}{25}$
Black Sea..................	21·60 = $\frac{1}{46}$	Atlantic at Equator...	39·42 = $\frac{1}{25}$
Arctic Sea..................	28·30 = $\frac{1}{35}$	South Atlantic..........	41·20 = $\frac{1}{24}$
Irish Sea....................	33·76 = $\frac{1}{30}$	North Atlantic..........	42·60 = $\frac{1}{23}$
British Channel........	35·50 = $\frac{1}{28}$	Dead Sea..................	385·00 = [illegible]

TABLE

SHOWING THE BOILING-POINT OF SALT-WATER AT THE DIFFERENT DE GREES OF DENSITY, WHEN THE BAROMETER STANDS AT 30 INCHES.

	SATURATION.	BOILING-POINT.
Fresh water.....	....	212 ° Fah.
Sea-water.........	$\frac{1}{32}$	213·2 "
"	$\frac{2}{32}$	214·4 "
"	$\frac{3}{32}$	215·5 "
"	$\frac{4}{32}$	216·7 "
"	$\frac{5}{32}$	217·9 "
"	$\frac{6}{32}$	219·1 "
"	$\frac{7}{32}$	220·3 "
"	$\frac{8}{32}$	221·5 "
"	$\frac{9}{32}$	222.7 "
"	$\frac{10}{32}$	223·8 "
"	$\frac{11}{32}$	225·0 "
"	$\frac{12}{32}$	226·1 "

The meaning of the term saturation, in its relation to the wat *of marine boilers,* means the quantity of salt it contains per gall

'ation at $\frac{1}{32}$ means 4 oz. salt to one gallon fresh water; z. salt to one gallon water; $\frac{3}{32}$, 12 oz. salt to one gallcn ınd so on. In carrying the water at $\frac{3}{32}$, twice as much is ed into steam as is blown off. At $\frac{2}{32}$, the water blown off .t converted into steam are equal. At $\frac{1\frac{3}{4}}{32}$, the water con- into steam equals $\frac{3}{4}$ of the water blown off.

following table shows the method of regulating the satura- 00 gallons of water, which is supposed to contain 7200 oz. being made the basis of the calculation.

	Water in Gallons.	Salt in Ounces.	
	600	7200	
out . .	200	2400	
at $\frac{1}{32}$ to make	400	4800	
r deficiency .	200	800	
	600	5600	
	200	steam	$\frac{1}{3}$ evaporated.
	400	5600	
. . .	200	800	
	600	6400	
	200	steam	$\frac{1}{3}$ evaporated.
	400	6400	
. . .	200	800	
	600	7200	

following ***calculation*** *shows* the loss induced by blowing *ell as the gain derived from* fresh-water condensers, prc viding they are tight, and the condensation of the steam be perfect. The degrees of heat imparted to the water converted into steam are the total heat of the steam minus the degrees of heat in the feed-water. The heat lost by blowing off is the difference between the heat of the feed-water and the sensible heat of the steam.

Rule for finding the percentage of loss induced by blowing off to prevent saturation.

Multiply loss by blowing off by 100, and *divide* the product by the total degrees of heat imparted to the water plus the heat lost by blowing off. (Observe that for $\frac{3}{32}$, as twice as much water is converted into steam as is blown off. For $\frac{2}{32}$, the amount is equal. For $\frac{1\frac{3}{4}}{32}$, the amount is $\frac{3}{4}$, and so on.) The result is the percentage of loss.

Example. — $\frac{3}{32}$.

Feed-water, 110° ; total heat, 1193·45° ; sensible steam, 260°.

$260° — 110° = 150°$ heat lost by blowing off.

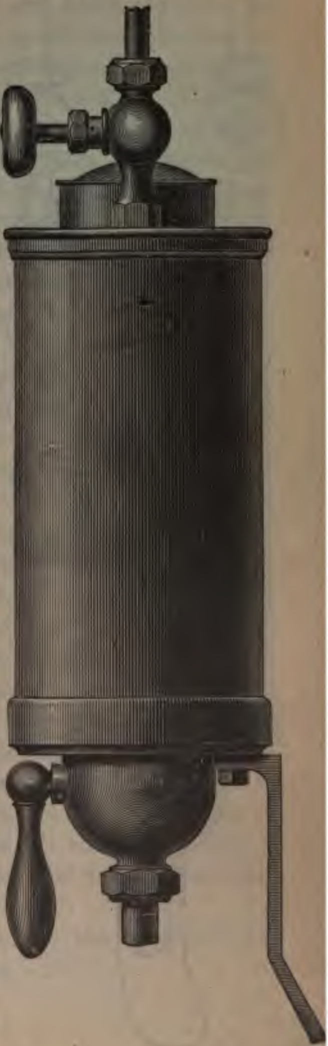
$1193·45° — 110° = 1083·45°$ total heat.

$1083·45° \times 2 = 2166·9° + 150° = 2316·9°$ total heat imparted, and loss by blowing off.

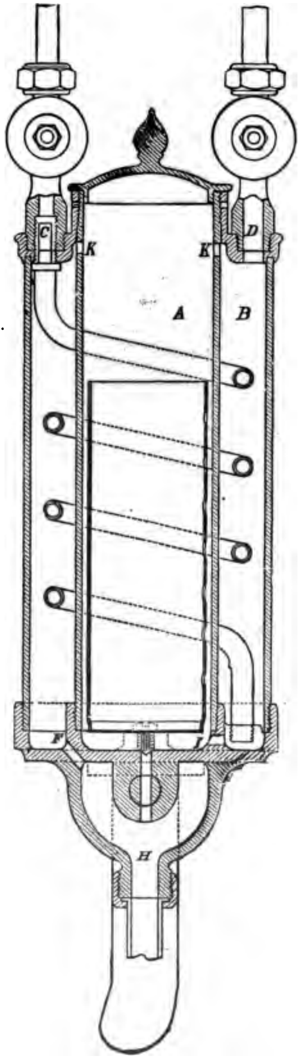
$(150° \times 100) \div 2316·9° = 6·47$ per cent. of heat lost by blowing off.

The cut on page 237 represents the Circulating Salinometer, which keeps up a continuous circulation, so that the degree of saturation can be observed at any moment, thus avoiding the necessity of frequently drawing off the water. This salinometer consists of a large and a small pot attached to the same bottom, one inside of the other, with a coil in the annular space between the two pots. This coil is connected at the top with a globe-valve, and at the bottom with a passage leading into the small or testing-cup, which contains a hydrometer and thermometer, the latter being hung by a spring hook on the upper edge of the pot. The right-hand globe-valve *is used for admitting* cold water into the annular space between

for the purpose of reducing the temperature of the water
ssage from the boiler to the
legree, so that it may rise in
g-pot perfectly quiescent, and
t the proper height; and the
n is maintained by openings
t near the top, through which
ws into the annular space be-
e two pots, after which it es-
h the cold water by the escape-
ugh the passage-way, making
connection at the bottom.
ssages are situated upon each
t and left, and, should they
hoked by sediment resulting
ldy water, they can be cleaned
lisconnecting the escape-pipe
ning a wire through them.
-cock at the bottom is only
emptying the testing-pot when
and has no communication
thing else.



ater from the boiler and the
er can in no way become
xcept by the bursting of the
h is not likely to happen un-
ould be left full of water and
o freeze. The coils are thor-
ested before they are put in;
s not specially designed to be
nothing can escape from the
it the cold water, and that
n the annular space is allowed
e full, which is unnecessary,
small quantity of cold water



will be sufficient to reduce the temperature of the water
through the coil. A hole is d
the back of the large pot, ı
top, which allows the water t
in case it should accidentally
full. The cold water is suppl
pipe connected by a globe-valv
pipe or valve below the water-
plying cold water, and led to
nometer. If it should be de
place the salinometer above
side water-level, the cold wate
supplied by some of the pum

In erecting these salinomet
may be secured to the boilers
head, but when there are two
boilers, a very neat and co
arrangement may be made b
them close together on a plain
plate fastened down with tap-b
with the pipe for the cold wat
just above them, with a T
and branch to each one, the pla
secured with tap-bolts in any
ient place in the engine-ro
salinometer may be attached
boiler, and all of them suppl
cold water from the same pipe
may be connected with two
boilers.

It is preferable to have o
nected with each boiler, as in t
the density of the water may
served in any boiler indepen
the others. To put the salin

ion, it is only necessary to open the valve communicating
en the boiler and the salinometer, and admit the water as
the overflow will allow it to escape, and when the temper-
reaches the required degree, the communication may be suf-
ly closed only to allow the necessary circulation. Then the
ater valve may be opened, and, if the connection with the
has considerable length of pipe to retain cold water, the
ff cock may be opened to admit of its escape, and then
. A very slight opening of either valve will be sufficient
p up the circulation and keep the water at the required
rature. If the water should be admitted too rapidly from
pressure, the agitation of the water at the bottom, even
the boiling-point, will disturb the hydrometer. When the
tion and temperature are properly adjusted, it will not re-
to be touched from one end of a passage to another, unless
be to adjust the cold-water valve occasionally if any con-
ble change takes place in the temperature of the water in
iler.

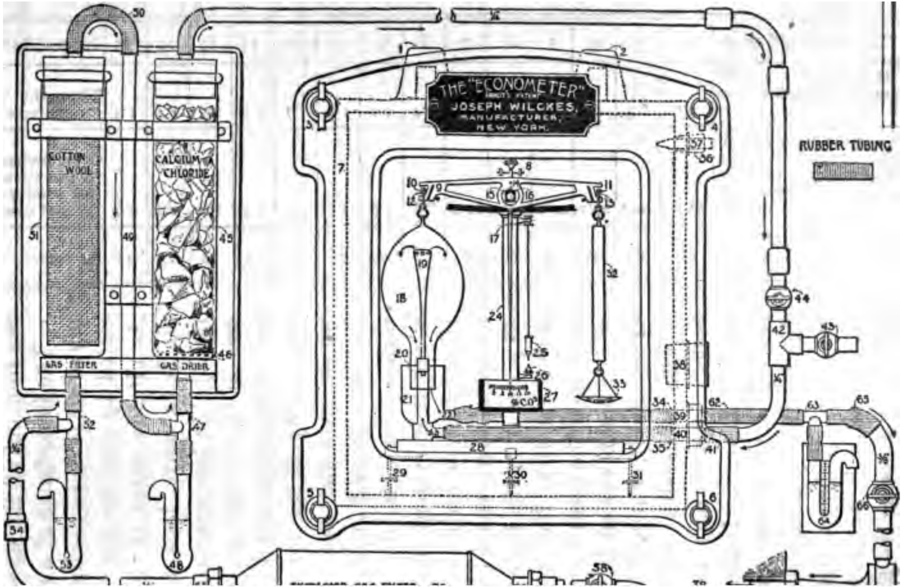
manipulation and operation of these salinometers are very
and satisfactory, as they are a decided improvement on any
arrangement of the kind ever heretofore used for the same
se, as, with one of them attached to each boiler, the density
water may be accurately determined at any moment, which
eature of great importance in many respects, and a fact
will be appreciated by those who have used other arrange-
The different parts of the salinometer are designated as
s: *A*, hot-water pot; *K*, outlet for hot-water overflow; *B*,
ater reservoir; *H*, general outlet; *C*, hot-water inlet to
, outlet passage from hot-water pot; *D*, cold-water inlet; *f*,
pot for hydrometer; *I*, passage from coil to hot-water pot;
let for cold water.

se salinometers are manufactured by the Crosby Steam
and Valve Company, Boston, Mass.

The Econometer.

In order to insure economy in firing, one of the most imp tant considerations is that the supply of air to the furnace shall sufficient for complete combustion of the fuel, but not greatly excess of this amount, because if too much air is admitted a ce tain portion of the heat of combustion will be used to raise th temperature of the excess and will thus be wasted. In order determine this point it has been the custom to make chemic analyses of the flue gases from time to time, and from the percen age of carbonic acid contained in them to decide whether or n the amount of air admitted was the most advantageous. A te of this kind necessitated the drawing off of a sample of the ga keeping it in a sealed tube, and making a chemical analysis the Hempel or Orsatt apparatus, which is a somewhat tedio operation.

The Econometer is an apparatus invented by Dr. Arndt, of Ge many, whose object it was to have a gauge that would regist continuously and automatically the percentage of carbonic acid the flue gases. The device, which is illustrated in the accompan ing cut, consists essentially of a glass bulb and a balance which used for weighing continuously the combustion gases as they pa through the bulb. Referring to the cut, 61 is the connection the boiler flue, where the gases enter the apparatus. They n pass successively through the three filters 55, 51, and 45, in ord to remove all dust and moisture, and then enter the instrum [illegible]. The gases issue from the funnel 19, [illegible] the surrounding air, and also on account [illegible] they descend and leave the bu through [illegible] Continuing through this tube they retu again [illegible] the chimney. The bulb, 18, counterpoise [illegible] and the instrument is adju by means [illegible] pointer stands at zero when passing [illegible] scale is graduated so that t [illegible] percentage of carbonic acid in


COTTON WOOL
CALCIUM CHLORIDE
GAS FILTER
GAS DRIER
THE "ECONOMETER"
JOSEPH WILCKES,
MANUFACTURER,
NEW YORK.
RUBBER TUBING

For Coal of medium q

the "Econometer" shows	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Per cent. carbonic acid
Then the quantity of air passing through the flues is	9·5	6·3	4·7	3·8	3·2	2·7	2·4	2·1	1·9	1·7	1·6	1·5	1·4	1·3	Times the theoretical requirements.
With a surplus supply of air of 30°/₀ or about 10.4 Cub. M. of necessary air per kilo. of fuel, there will still be a further excess of about ..	65·6	40·0	27·2	20·0	15·2	11·2	8·8	5·6	4·8	3·2	2·4	1·6	0·8	0·0	Cubic metres of superfluous air heated to a temperature of usually 270° Centigrade.
And the loss of fuel at 270 C amounts to	90	60	45	36	30	26	23	20	18	16	15	14	13	12	Per cent.

gases, and hence the reading
apparatus are a continuous
of the composition of the gas
ing from out of the stack.

**The importance of a corre
ply of air** to boiler furnaces i
ciated by very few users of
As already stated, if the su
air is excessive, heat is wa
raising the temperature of
cess to that of the gases.
tent of this waste will be app
by a study of the following
which gives the loss of he
fuel with from 2 to 15 per
carbonic acid in the gase
which it is evident that ev
10 per cent. of carbonic acid
flue gases there would be a v
18 per cent. of the fuel, whil
percentage is as low as 4 (w
very often the case) nearly c
of the fuel is wasted in hea
excess supply of air.

This excessive air su
boiler furnaces may be du
variety of causes. In most c
grate is not correctly prop
for the quality of the coal,
generally too large. It m
be, and often is, due to poo
the stoker allowing the form
holes in the fire through
large volume of air finds its
the flue, or it may be due

position of the damper. In any case, the defect should be d, and, in order to do this, it must first be located, and this function of the econometer. The instrument has been hly tested and its readings correspond with the results of l analysis to a fraction of 1 per cent.

smaller devices used in the boiler room, and in connec- h boilers, such as back-pressure valves, reducing valves, alves, blow-off cocks, gauge cocks, water gauges, steam , pressure regulators, damper regulators, etc., etc., are all importance, but they are too numerous to mention, specifi- n this book. It is essential, however, that everyone in of steam plants should be familiar with these devices, and r of this book is referred to manufacturers' catalogues, an usually be had on application, for a detailed descrip- he various boiler appliances mentioned above.

CHAPTER XIII.

FEED PUMPS AND INJECTORS.

Pumps.

s, **of whatever** design or construction, or for whatever pur- ployed, are simply hydraulic machines attached to one tube, for the purpose of raising, or transferring water, or other or fluids. The idea entertained y that water is raised by suction eous, as, properly speaking, there ch principle as suction. Atmos- 'lift" or "suction" pumps cause ter to raise itself by having its *relieved of the column of air* *ipon it. If, therefore,* one end of a pipe or tube be lowered

into water, the other end be closed by means of a valve or o device, and the air contained in the pipe be drawn out, it is dent that the surface of the water within the pipe will be relie of the pressure of the atmosphere. There will then be no re ance offered to the water to prevent its rising in the tube. water outside of the pipe, still having the pressure of the at phere upon its surface, therefore forces water up into the pipe, s plying the place of the excluded air, while the water inside pipe will rise above the level of that outside of it, proportion to the extent to which it is relieved of the pressure of the air; that, if the first stroke of a pump reduce the pressure of the contained in the pipe from 15 pounds per square inch (which i normal pressure) to 14 pounds, the water will be forced up the to the distance of about 2¼ feet, since a column of water an i square, and 2¼ feet high, is equal to about one pound in weig

It is evident that, upon the reduction of the pressure of the contained in the pipe from 15 to 14 pounds per square inch, th will be (unless the water ascended the pipe) an unequal pr ure upon its surface inside as compared to that outside of pipe; but, in consequence of the water rising 2¼ feet in the p the pressure on the surface of the water, both inside and outs is evenly balanced (taking the level of the outside water to be natural level of the water inside), as the pressure upon the w exposed to the full atmosphere is 15 pounds upon each squ inch of its surface, while that upon the same plane, but wit the pipe, will sustain a column of water 2¼ feet high (weigh one pound) and 14 pounds pressure of air, making a total of pounds, which is, therefore, an equilibrium of pressure over whole surface of the water at its natural level.

If, in consequence of a second stroke of the pump, the pressure in the pipe is reduced to 13 pounds per inch, the wa will rise another 2¼ feet. This rule is uniform, and shows t the rise of a column of water within the pipe is equal in wei *to the pressure of* the air upon the surface of the water witho *hence it is only* necessary, to determine the height of a colum ter that will weigh 15 pounds per square inch of area at the se, to ascertain how far a suction-pump will cause the water to e. It must be understood, that the distance varies with the ight above sea level, and also with the pressure of the atmos- ere. At our level of the sea, the column of water that the mosphere will support is about 33 feet in height, and a pump ll "draw water" (as it is called) this distance; but the force hich sends the water into the pump at this height is so dimin- hed as to be almost balanced by its own weight; hence a lifting- mp will deliver water very slowly, drawing it this distance.

To be reliable, the cylinder and piston should be in good order, l the joints perfectly air-tight, a check-valve be placed in the wer end of the suction-pipe; and even then the pumps should run at a high speed. Pumps will give more satisfactory results hen the lift is from 22 to 25 feet. There is hardly any limit to e distance a pump will draw water through a horizontal suction- pe, provided the pipe is perfectly tight, and everything is so pro- rtioned as not to cause undue friction.

The capacity of any pump may be determined by multiplying e area of the piston in inches by its stroke in inches, giving the mber of cubic inches per single stroke; this divided by 231 (the mber of cubic inches in a standard gallon) will give the number gallons per single stroke; but it must be remembered that all mps throw less water than their capacity, the deficiency rang- g from 20 to 40 per cent., according to the quality of the pump. his loss arises from the lift and fall of the valves, from inaccuracy fit or leakage, and in many cases from there being too much space tween the valves and piston, or plunger. The higher the valves any pump have to lift to give the necessary opening, the less ficient the pump will be.

The power required to raise a given quantity of water a certain eight may be computed by the following rule: Multiply the mount of water in gallons to be raised per minute by 8·35 lbs. the weight *of a gallon of water), and* this product by the height, in *t, of the discharge from the point* of suction; divide the result by

33,000, which will give the theoretical horse-power required to r the amount of water to a certain distance. The actual ho power which would be required to do this work is always c siderably in excess of the theoretical, because there are ma sources of loss in pumping water. These losses are due to vari causes. In the first place, there are the losses in the pump its incurred in the friction of the moving parts, lifting the valves, These are greater, in proportion, for small pumps than for la ones, and in small boiler feed pumps are often as high as 50 cent. of the total power required. The other principal source loss of power lies in the friction of the water in the piping, a this loss is proportional to the square of the velocity of the fl Hence, the velocity of the water should be kept as low as po ble by making the pipes of ample diameter. Bends in piping, fittings, valves, and other obstructions should also avoided in order to make the losses of power in the pipes small as possible. A table of power will be found on page 14

To find the proper capacity of a pump to feed a given boi it is necessary to know how much water the boiler is capable evaporating. On the basis of the Centennial Rating (see p. 1 each horse-power of boiler capacity corresponds to an evaporat of thirty pounds of water per hour. The pump, however, sho be capable of supplying all of the water when the boiler is forc furthermore, it is better to operate a pump slowly and c tinuously, and for these reasons the pump running at its nor speed should be capable of supplying about twice as much wa as the boiler evaporates under usual conditions. In determin the dimensions of the pump, the velocity of the water in it sho not exceed 500 feet per minute.

Boiler feed pumps belong to that class of pumping machi known as force pumps; that is, those which force water against opposing pressure at the point of delivery, as distinguished fr lift pumps, which lift the water and deliver it under atmosphe *pressure. They* may be classified as follows, according to *nethod employed* in driving them:

(*a*) Power pumps.
(*b*) Electric pumps.
(*c*) Steam pumps, { Direct acting,
Fly wheel,
Duplex.

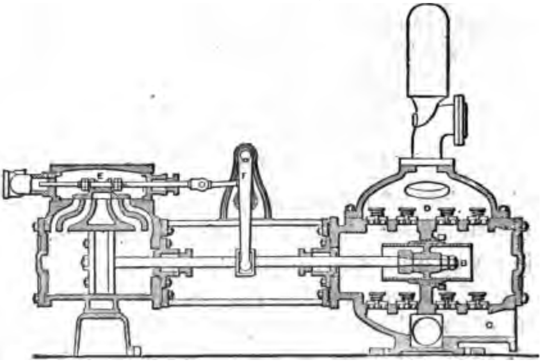
Power pumps are those in which the power used to drive them i supplied from some external source and is transmitted to the ump proper by means of pulleys and belts, toothed gearing, riction clutches, or other device for transmitting power. This lass of pumps is not much used for boiler feed purposes.

Electric pumps are those which are geared or directly connected to electric motors. Like power pumps, these are not uch used to feed boilers, because in transforming the energy f the steam first into mechanical power, then into electrical, and inally back again into mechanical power, additional and unnecesary losses are incurred. Electric pumps are used mainly where lectrical energy only is available, or where it is not desirable to ave an unsightly system of steam and exhaust pipes.

Steam pumps are now used almost universally for the purpose f feeding boilers. They are divided into three general classes:

Direct acting pumps,
Fly-wheel pumps,
Duplex pumps.

The main points of difference in these three classes lie in the ethod of getting past the dead centre. If a pump were contructed simply by using two cylinders with pistons attached to the pposite ends of a common piston rod, the one end being used like he cylinder of an ordinary steam engine, with its slide valve, etc., nd the other end for pumping the water, there being no rotary otion of any kind in the mechanism, it is evident that the achine would come to rest at the end of each stroke unless some xternal method were employed for helping it over its dead centre. his, of course, *could be easily done* by simply adding a crank-*haft and a flywheel of sufficient* weight to carry the engine over the dead points. This is exactly what is done in flywheel pum but, inasmuch as no rotary motion is required for driving t pump, except to carry it over the dead points, it has occurred builders of pumps that some simpler method might be devis These considerations have led to the invention of the direct acti pump, which consists essentially of the two cylinders and pist as described above, with a suitable slide valve for distribut steam, and in addition an auxiliary valve or valves operated b suitable mechanism to admit steam behind the piston when i on what would ordinarily be the dead centre. Many differ designs of this type have been placed on the market, notably "Knowles," "Blake," "Deane," "Cameron," and others, all which operate successfully without crank shaft or flywheel. only objection to pumps of this kind is that they are necessa somewhat complicated, and while their operation has proved v satisfactory, they are not used as extensively as the last-na type, the duplex pump, which is much simpler in its action.



The Worthington Steam Pump. Sectional view.

The duplex steam pump is virtually a combination of *pumps so coupled* that the slide valve of the one is opera *from the piston*-rod of the other, and vice versa. In this is no dead centre, and, furthermore, no auxilary valves echanism of any kind are required to accomplish this end. sectional and perspective views illustrate the Worthington , which is perhaps the most widely used make of the duplex of pump. It will be seen from these cuts that the valve is a (*D*) slide valve operated by a vibrating arm, *F*, which swings gh the whole length of the stroke. The one piston acts to steam to the other, after which it completes its stroke and

The Worthington Boiler Feed Pump.

remains at rest until its valve is acted upon by the other , before beginning its next stroke. As one or the other of wo valves is always admitting steam, there can be no dead , and the pump may therefore be started in any position by y opening the throttle valve. The plunger, *B*, is double-g; that is, when water is taken in on one side it is dis-ged on the other. *C* is the suction and *D* the discharge ber.

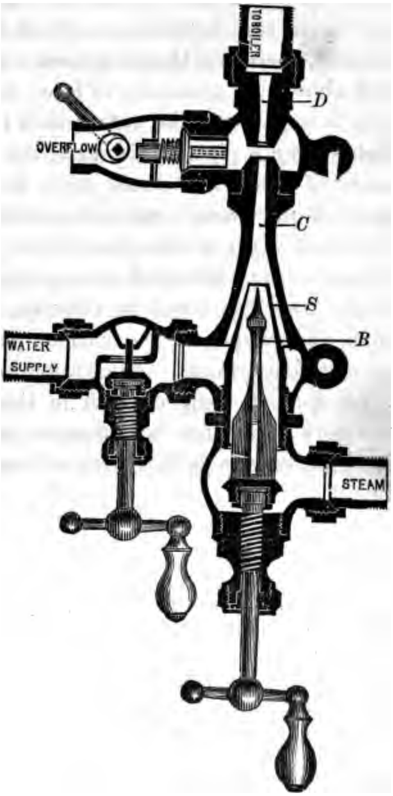
hen hot water passes through the pump certain conditions which must be met by special devices. It has been found hot water cannot be lifted successfully, because as the plunger s *forward and creates* a vacuum in the suction pipe, the re *being relieved, to* a sufficient extent, the water will evaporate and the pump cylinder will be filled with steam vapor, instead of with water. To avoid this the pump should placed below the level of the water in the supply tank or heat so that it will follow the plunger by the action of gravity. Pum for hot water should be lined with brass to avoid corrosion, a linen packing should be used, as rubber will disintegrate unc the action of heat. It is also customary to place a pipe with valve between the heater and the pump, so that any vapor whi may collect can be liberated.

Injectors.

The injector may be defined as an apparatus in which a jet steam strikes a mass of water, by which it is condensed, and condensing gives up its heat energy to the combined mass water and condensed steam, and imparts to it a momentu sufficient to force it into the boiler against a pressure equal or even greater than that of the steam which first entered t apparatus.

The invention of the injector is due to the French engine Giffard, who in his description of the apparatus states that "of the necessary accessories of a steam engine perhaps the mo important is the one used for feeding the water to the boile upon its proper working depends not only the regular running the engine, but the safety, the very existence of those who approa the boiler; . . . nevertheless, by a kind of fatality the app ratus employed, up to the present time, for feeding is, of others, that which leaves most to be desired." There is no dou that his invention is by far the greatest advance in this dire tion since steam was first utilized as a motive power, and it safe to predict that so long as steam is used as a motive power long will the injector be used as a means of conveying wat to the boiler.

he action of the injector may be briefly explained as follows *nsists* essentially of a steam tube or steam nozzle, S, which ed for the purpose of guiding the steam jet into the apparatus. his is usually of tapering rm, as shown in the cut, and equently carries a *steam indle*, *B*, used for varyng the area of discharge rom the nozzle by adjusting s position from without; a *ombining tube*, *C*, which exends from the steam nozzle utward and has for its obect the combining of the team and the water, and a *elivery tube*, *D*, from which he mixture of steam and vater is delivered to the oiler feed pipe. The mixure attains its maximum veocity in the delivery tube, hich is subsequently reduced y increasing the cross secion of the tube. The steam nters at the opening marked steam" in the diagram, and asses through the steam nozle into the combining tube. n first starting the injector he steam passes on through e combining tube, and, being unable to re-enter the boiler because has been somewhat reduced in pressure, passes out of the "overow." In a very short time, however, the friction between the r in the apparatus and the steam jet causes a partial vacuum in e combining tube, and the water now rises into this tube, and, mbining *with the steam*, causes the latter to be condensed. The ss *section of the condensed* steam jet is now greatly reduced



and its velocity is about twenty times as great as that of
water issuing from the boiler at the same pressure, and
velocity is concentrated on a jet of very small cross sectic
evident, therefore, that it possesses a large margin of ene
and above that necessary to force it into the boiler, and
plus is imparted to the water which has been drawn in thr
water supply pipe. Of course, the proportions between
umes of steam and water must be correctly chosen, be
there is not enough water to condense the steam the a
described will not take place, while if there is too much
energy of the condensed steam jet will not be sufficient to
whole mass the requisite velocity. For this reason the
tions and shapes of the various parts of an injector a
greatest importance. Much experimentation and study h
applied to this subject, both in this country and abroa
the work which has been done in this connection, that c
land L. Kneass is deserving of especial attention. Th
this book is referred to his work on the "Practice and T
the Injector," if he desires to familiarize himself more th
with the subject.

The failure of injectors to work may be due to a v
causes. The most common of these is the presence of a
suction-pipe, due to leaks in the joints or improper pa
valve stem. The suction pipe must be made air-tight
end of the pipe must be submerged in water, otherwise a
sucked in and the injector will not work. Sediment and
the nozzles are other causes of injectors failing to work,
point should be looked after from time to time. W
injector fails to get water there may be a leak in the sup
the water supply may be cut off, the strainer may be cl
the water may be too hot, or the pressure may be too lo
required lift. If it gets water, but fails to force it into t
the water supply is probably not properly adjusted to t
v, or it may be due to an obstruction in the check
d pipe, or the delivery tube of the injector.

ed water to the boiler, but *breaks*, the fault may lie in any one e above causes, or it may be that a globe valve in the supply has a loose disc which partly closes the valve after the ;or is started. This may be remedied by reversing the

ectors may be classified as follows:*

igle jet injector, one in which a single set of combining and ery tubes is used.

uble jet injector, one containing two sets of steam jet atus, of which the first or lifting set receives the feed- from the source of supply and delivers it to the second cing set, from which it receives sufficient impulse to enter oiler.

omatic or re-starting injector, one that is able to re-estab- utomatically the continuity of the jet, after a temporary uption in the steam or water supply.

f-adjusting injector, one in which the supply of water is iatically adjusted to suit the steam supply without waste at erflow.

en overflow injector, which has one or more apertures in the ining tube, opening into one or more overflow chambers, that be closed against the admission of air by the use of light valves opening outward.

sed overflow injector, which can only start by means of an ng or vent placed beyond the delivery tube, which must be l in order to divert the jet into the boiler.

m a practical standpoint they may be classified as:

ting injectors, in which there is a partial vacuum formed in ed-pipe preliminary to starting.

n-lifting injectors, which require a pressure in the water y.

e injector was first introduced in this country by William s & Co., Incorporated, of Philadelphia, who have done much to develop and perfect it. It will be appropriate, therefoı begin with a description of the various injectors manufacturı this company, and to follow this with an account of a few o other types which have been successful. The illustrations aı panying the descriptions are taken largely from the Catalogı Narrow Gauge Locomotives, issued by the Baldwin Locom Works, Philadelphia.

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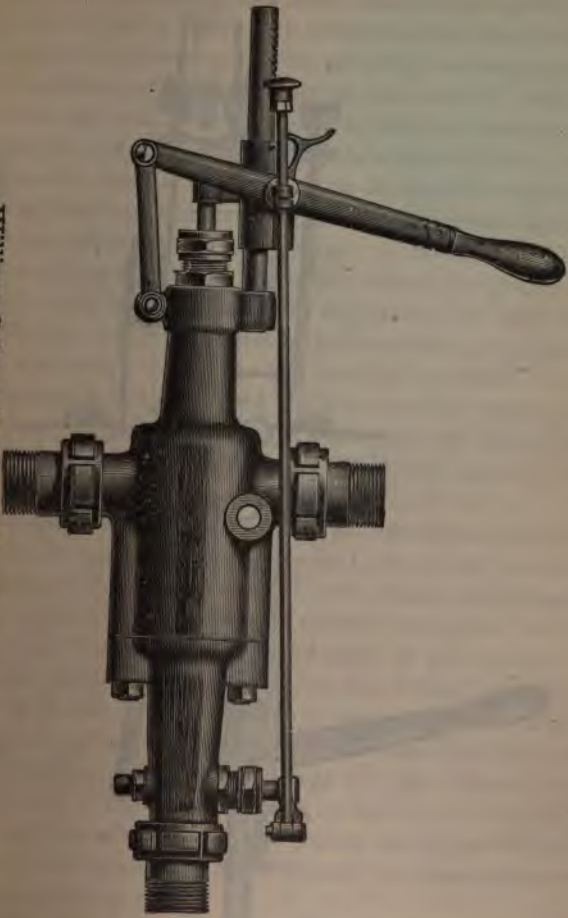
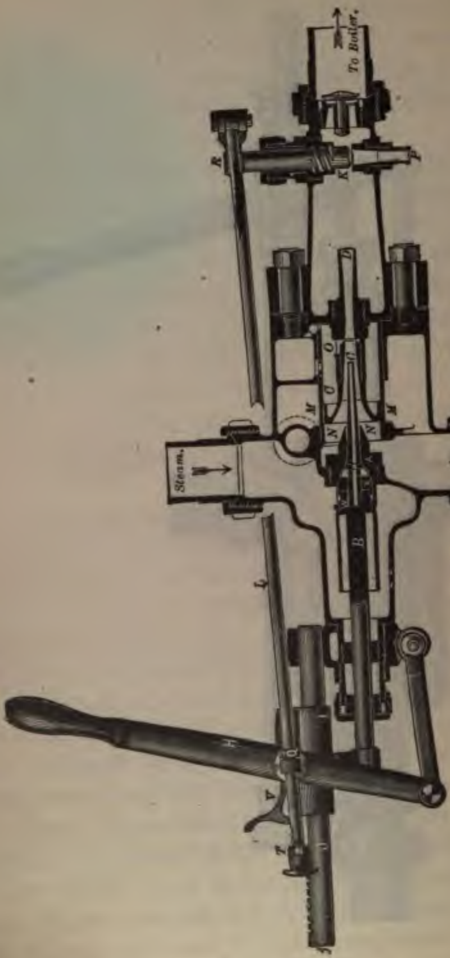
* *Strickland L. Kneass, Practice and Theory of the Injector.*

William Sellers & Co.'s Injectors.—The cut on page 255 r sents Sellers' lifting injector of 1876, so extensively used on motives, steamships, tugs, and ferries. It is a self-contained in ment, that is to say, it has both steam- and check-valves, so it can be connected directly, without any other fittings; althı of course, it is desirable to place another stop-valve in the st pipe and a check-valve in the delivery-pipe, so that the inj can be taken to pieces, or disconnected at any time. Anı important feature of this injector is, that it is operated by a s handle, and that the waste-valve is only open at the instaı starting.

Its internal mechanism and mode of action may be easil derstood by referring to the sectional cut on page 256. *A* is receiving-tube, which can be closed to the admission of stean the valve *X*. A hollow spindle passing through the receiı tube into the combining-tube, is secured to the rod *B*, and valve *X* is fitted to this spindle in such a way that the latteı be moved a slight distance (until the stop shown in the fi engages with valve *X*) without raising the valve *X* from its A second valve, *W*, secured to the rod *B*, has its seat in the u side of the valve *X*, so that it can be opened (thus admitting sı to the centre of the spindle) without raising the valve *X* froı seat, if the rod *B* is not drawn out any farther after the sto the hollow spindle comes in contact with the valve *X*. *D* is delivery-tube, *O* an overflow opening into space *C K*, the cı valve in delivery-pipe, and *P R* the waste-valve. The upper of the combining-tube has a piston, N N, attached to it, cap of moving freely in a cylindrical portion of the shell, M N



William Sellers & Co.'s Lifting Injector.



Section of William Sellers & Co.'s Lifting Injector.

e lower end of the combining-tube slides in a cylindrical guide rmed in the upper end of the delivery-tube.

The rod B is connected to a cross-head which is fitted ove e guide-rod, J, and a lever, H, is secured to the cross-head. A d, L, attached to a lever on the top end of the screw waste-valve sses through an eye that is secured to the lever H; and stops , Q, control the motion of this rod, so that the waste-valve i sed when the lever H has its extreme outward throw, and i ened when the lever is thrown in, so as to close the steam-valve , while the lever can be moved between the positions of the stops , Q, without affecting the waste-valve. A latch, V, is thrown o action with teeth cut in the upper side of the guide-rod, J hen the lever H is drawn out to its full extent, and then moved ck; and this click is raised out of action as soon as it has been oved in far enough to pass the last tooth on the rod J. An air- ssel is arranged in the body of the instrument, as shown in the ure, for the purpose of securing a continuous jet when the in- ctor and its connections are exposed to shocks, especially such occur in the use of the instrument on locomotives.

The manipulation required to start the injector is exceedingly mple,— much more so in practice, indeed, than it can be rendered description. Moving the lever H until contact takes place be- een valve X, and stop on hollow spindle, which can be felt by e hand upon the lever, steam is admitted to the centre of the indle, and, expanding as it passes into the delivery-tube D, and aste-orifice P, lifts the water through the supply-pipe into the mbining-tube around the hollow spindle, acting after the manne f an ejector or steam-siphon. As soon as solid water issues through e waste-orifice P, the handle H may be drawn out to its full ex- nt, opening the steam-valve X and closing the waste-valve, when e action of the injector will be continuous as long as steam and ter are supplied to it.

To regulate the amount of water delivered, move in the leve until the *click engages any of* the teeth on the rod J, th *iminishing the steam-supply,* as the water-supply is self-regu ing. If too much water is delivered, some of it will escape throug *O* into *C*, and, pressing on the piston *N N*, will move the con bining-tube away from the delivery-tube, thus throttling the wate supply; and if sufficient water is not admitted, a partial vacuu will be formed in *C*, and the unbalanced pressure on the upper sid of the piston, *N N*, will move the combining-tube towards the d livery-tube, thus enlarging the orifice for the admission of wate The injector, once started, will continue to work without any furth adjustment, delivering all its water to the boiler, the waste-val being kept shut. By placing the hand on the starting-lever, it easy to tell whether or not the injector is working; and if desire the waste-valve can be opened momentarily by pushing the rod J a knob on the end being provided for the purpose.

TABLE

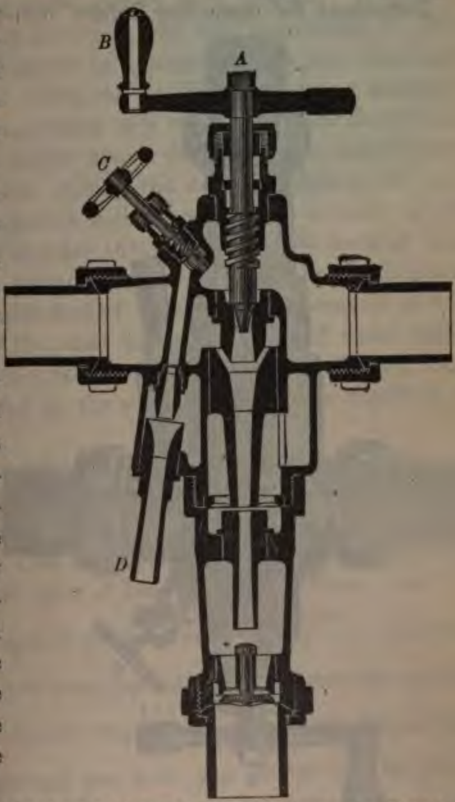
SHOWING STEAM-PRESSURE REQUIRED TO LIFT AND DELIVER WATER WI SELLERS' FIXED-NOZZLE LIFTING INJECTOR.

HEIGHT WATER IS LIFTED.		STEAM-PRESSURE REQUIRED TO LIFT AND DELIVER WATER.	HEIGHT WATER IS LIFTED.		STEAM-PRESSURE REQUIRED TO LIFT AND DE LIVER WATER
Feet.	Inches.	Lbs. per Sq. In.	Feet.	Inches.	Lbs. per Sq. In
3	0	25	21	3	52
5	0	30	22	10	60
11	6	40			70
15	0	49			100

Sellers' Non-Adjusting Fixed-Nozzle Injector with Liftin Attachment, for Stationary Boilers.

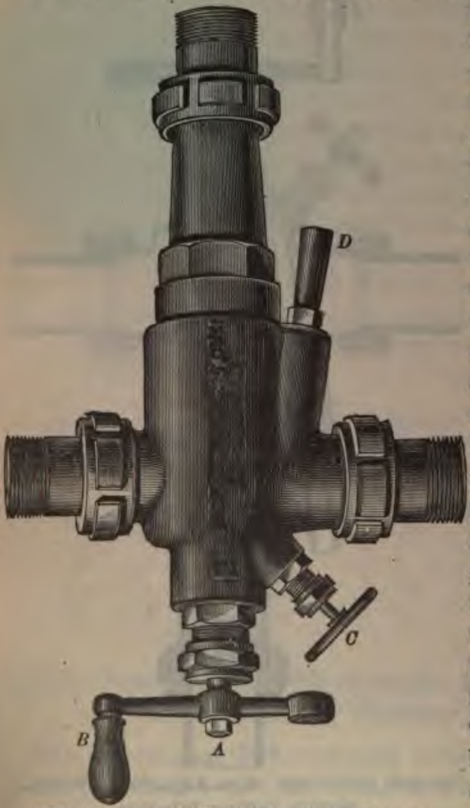
The cut on page 259 represents Sellers' Non-Adjustable I jector with fixed-nozzle and lifting attachment. As will be o served, a steam-ejector or siphon is attached to the side of th instrument, which draws the water, when lifted by the admissic *of the steam*, through the combining-tube, and discharges 'ugh the orifice of the lifting attachment, through which, a water or overflow escapes. This injector has a check-nected to it, also a steam stop-valve, which can be opened half a revolution of the lever on the stem. In connecting tor, since it has fixed nozzles, a water-supply valve must ded, and, as al-marked, a sec-ck-valve in the -pipe and an-eam-stop valve able.

rting this injec-n is first admit-e lifting-nozzle, er-supply valve djusted so as to about the max-mount of water nding to the essure; and as solid water is-m the lifting-the steam-valve opened slightly e jet is estab-when the full essure is to be d, and the valve nits steam to the ozzle is to be **little dexterity** red to start the for a maximum lift, but the manipulation is readily ac-while *for all ordinary lifts* no special care is required. As *ity of steam escaping* from an orifice varies greatly with



Section of Sellers' Non-Adjustable Fixed-Nozzle Lifting Injector.

the pressure, other things being equal, the lifting-nozzle mus proportions depending on the minimum steam-pressure to l ployed, since it can readily be adapted to higher pressures b tially closing the steam-admission valve.



Sellers' Non-Adjustable Fixed-Nozzle Lifting Injector.

Directions for operating Sellers' non-adjustable fixed-i injector, with lifti tachment.—*Firs* the steam-spind by means of the h *B. Second*, open t ing-jet by backi wheel, *C*, one-q turn. *Third*, wh water escapes a overflow, *D*, ru the spindle, *A*, by ing it quickly; close the lifting-j as the injector wil be feeding the l and the water-s may be regulat means of an or globe-valve plac tween the inject the water sourc this valve is set mit the required tity of water, ther be no drip from overflow. Whe quired, a special lating valve, whi quires but one turn, and which indicates the required open ached to the injector, so that those having it in charge rmine the actual amount of opening by a glance at the hand-heel on the valve-spindle.

Duty of Sellers' injectors, or the foot-pounds of useful work erformed by the consumption of 100 lbs. of coal in the boiler pplying steam to the injector, may be of interest. When the vaporation of the boiler is known, this duty can readily be com-uted from the data obtained in connection with the maximum livery of the injector. This can be illustrated by an example. Assuming the boiler evaporation at 9 lbs. of steam per lb. of coal, result which, though rather above the average, is occasionally ceeded in good practice. Using the data recorded in the table page 416 for the maximum delivery at a steam-pressure of 130 bs. per square inch, it appears that 150 — 66 = 84 units of heat ere imparted to each pound of water delivered by the injector, nd, the weight of a cubic foot of water at a temperature of 66° ah. being about 62·3 lbs., that the total weight of water deliv-red per hour was 161·2 × 62·3 = 10,042·76 lbs., so that the total amount of heat imparted to the water per hour was 10,042·76 × 84 = 843,591·84 units.

The total heat above 32° in a pound of dry steam, at a pressure of 130 lbs. per square inch, is 1187·8 units, and the heat remaining in a pound of steam above 32°, after condensation, is 150 — 32 = 118 units, so that each pound of dry steam imparted 1187·8 — 118 = 1069·8 units of heat to the feed-water, and the weight of dry steam required per hour was $\frac{843,591\cdot84}{1069\cdot8} = 788\cdot6$ lbs. The height of a column of water equivalent to the pressure against which the water was delivered was $\frac{144 \times 130}{62\cdot3} = 300\cdot5$ feet, so that the useful work performed per hour was 10,042·76 × 300·5 = 3,017,049·38 foot-pounds. The weight of coal required to do this work, on the assumed boiler evaporation, was $\frac{788\cdot6}{9} = 87\cdot6$ lbs., so that the *duty of the injector,* per 100 lbs. of coal, was $\frac{3,017,049\cdot38 \times 100}{87\cdot6} \doteq 3,455,536$ foot-pounds.

The term range is frequently used in connection with injecto and means the difference between the maximum and minimu delivery.

TABLE

SHOWING THE MAXIMUM AND MINIMUM DELIVERY OF SELLERS' SEL ADJUSTING, 1876, INJECTOR NO. 6; TEMPERATURE OF DELIVERI WATER; PRESSURE AGAINST WHICH INJECTOR DELIVERS WATER, AI HIGHEST TEMPERATURE OF FEED ADMISSIBLE; WATER FLOWING 1 INJECTOR UNDER 15 INCHES HEAD; WASTE-VALVES SHUT.

Pressure of Steam Supplied to Injector, and Pressure against which Water is Delivered. *Lbs. per Sq. In.*	Delivery in Cubic Feet per Hour.			Temperature Fahrenheit Degrees.			Pressure of Steam Required to Deliver Water against Pressure in Column 1.	Highest Temperature admissible of Feed-Water, Fahrenheit Degrees.
					Delivered Water.			
	Maximum.	Minimum.	Ratio of Minimum to Maximum Delivery.	Feed-Water.	At Maximum Delivery.	At Minimum Delivery		
1	2	3	4	5	6	7	8	9
10	75·3	63·6	0·845	66	100	94	3	132
20	82·4	61·2	0·743	66	108	104	9	134
30	94·2	56·5	0·600	66	114	116	16	134
40	100·1	60·0	0·599	66	120	123	22	132
50	108·3	64·7	0·597	66	124	125	27	131
60	116·5	63·6	0·546	66	127	133	34	130
70	124·8	63·6	0·510	67	130	142	40	130
80	133·0	67·1	0·505	66	134	144	46	131
90	141·3	69·5	0·492	67	136	148	52	132
100	147·2	64·7	0·456	66	140	159	58	132
110	153·0	67·1	0·439	67	144	162	63	132
120	156·6	73·0	0·466	67	148	162	69	134
130	161·2	74·2	0·460	66	150	165	75	130
140	166·0	78·9	0·476	66	153	166	81	126
150	170·7	70·6	0·414	66	157	167	88	121

The table of capacities shows the maximum delivery, but th *injector can be* regulated so as to reduce the amount about 60 pe t.

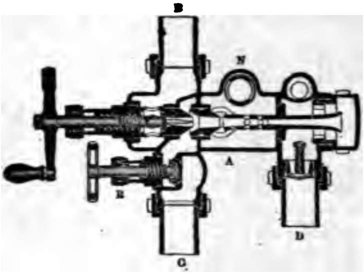
OF CAPACITIES OF SELLERS' INJECTORS.

Size of Injector.	Size of Pipe for Connections.	Pressure of Steam in Pounds.									
		10	20	30	40	50	60	70	80	90	100
		Cubic Feet of Water Discharged per Hour.									
No. 2	½ in.	8·3	·9	9·7	10·4	11·1	11·8	12·5	13·2	13·9	14·6
" 3	¾ "	19·27	21·04	22·81	24·58	26·35	28·12	29·89	31·66	33·43	35·2
" 4	1 "	36·66	39·6	42·74	45·88	49·02	52·16	55·3	58·44	61·58	64·72
" 5	1¼ "	57·58	62·5	67·42	72·34	77·26	82·18	87·1	92·02	96·94	101·86
" 6	1¼ "	83·48	90·6	97·72	104·84	111·97	119·09	126·21	133·33	140·45	147·57
" 7	1½ "	114·03	123·75	133·48	143·2	152·93	162·65	172·38	182·1	191·83	201·55
" 8	2 "	149·2	162·	174·8	187·6	200·4	213·2	226·	238·8	251·6	264·4
" 9	2 "	189·2	205·35	221·51	237·66	253·82	269·97	286·13	302·28	318·44	334·59
" 10	2 "	233·84	253·8	273·76	293·72	313·68	333·64	353·61	373·57	393·53	413·49
" 12	2½ "	337·2	366·	394·8	423·6	452·4	481·2	510·	538·8	567·6	596·4
" 14	2½ "	451·49	491·45	531·41	571·36	611·32	651·27	691·23	731·18	771·14	811·09
" 16	3 "	600·32	651·6	702·88	784·16	805·44	856·72	908·	959·28	1010·56	1061·84
" 18	3 "	760·07	825·	889·93	954·86	1019·78	1084·71	1149·64	1214·57	1279·5	1344·42
" 20	3½ "	938·84	1019·	1099·16	1179·32	1259·48	1339·64	1419·8	1499·96	1580·12	1660·28

TEMPERATURE OF FEED-WATER.

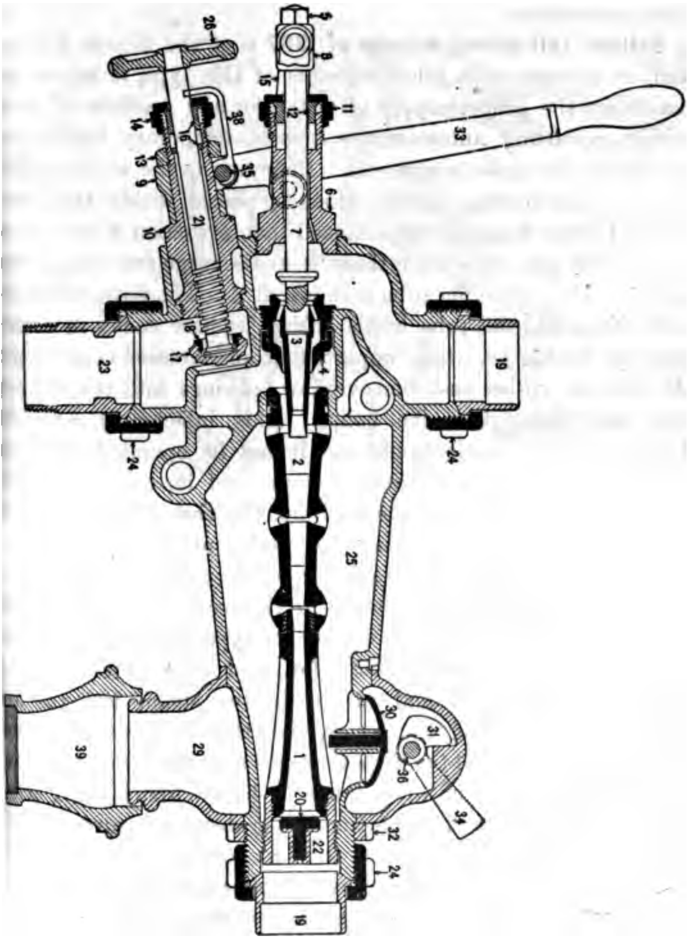
MAXIMUM TEMPERATURE OF FEED-WATER ADMISSIBLE AT DIFFERENT PRESSURES OF STEAM.

Pressure of Steam Pounds per Square Inch.........	10	20	30	40	50	100
Temperature of Feed-water, Fahrenheit.............	148°	138°	130°	124°	120°	110°



Sellers' fixed nozzle injector of 1885 is illustrated, in section, by the accompanying cut. It is a lifting injector—that is, it will receive water under pressure, or it will lift it to a considerabl height before delivering to the boiler. Moreover, it is automatic and restarting—that is, if the water and steam are turned on, it will start itself; and, should the jet be broken, it will re-establish itself as soon as the disturbing cause is removed. The automatic action is complete when the water enters the injector under pressure, and also when lifting to a height of eighteen feet with ordinary steam pressures, the amount of water delivered being regulated by a valve contained in the injector or by the adjustment of both the water-valve and steam-plug, as may be preferred. If the supply of water is too much reduced, steam will escape at the overflow, but the jet will not break.

When required to lift, the injector, at say 60 pounds steam pressure, will raise the feed water 23 feet. As a non-lifter it will take water at 137° Fahr. with the overflow-valve open, and at 150° Fahr. with the overflow closed. By reference to the sectional view it will be seen that the instrument is quite simple in its construction, notwithstanding its applicability to varied conditions of service: *A* is the body or case of the injector; *B* is the steam connection leading from the steam-space in the boiler; *C* is e water-supply connection, in which is situated the water-regu- ting valve *R*; *D* is the water delivery connection, containing a eck-valve, and leading to the boiler. The overflow-valve *N* may be shifted to either side of the injector body and turned radially, so that the injector may be placed in any position that will per- *discharge* the overflow vertically downward. Another nd exceedingly convenient feature of the constructio

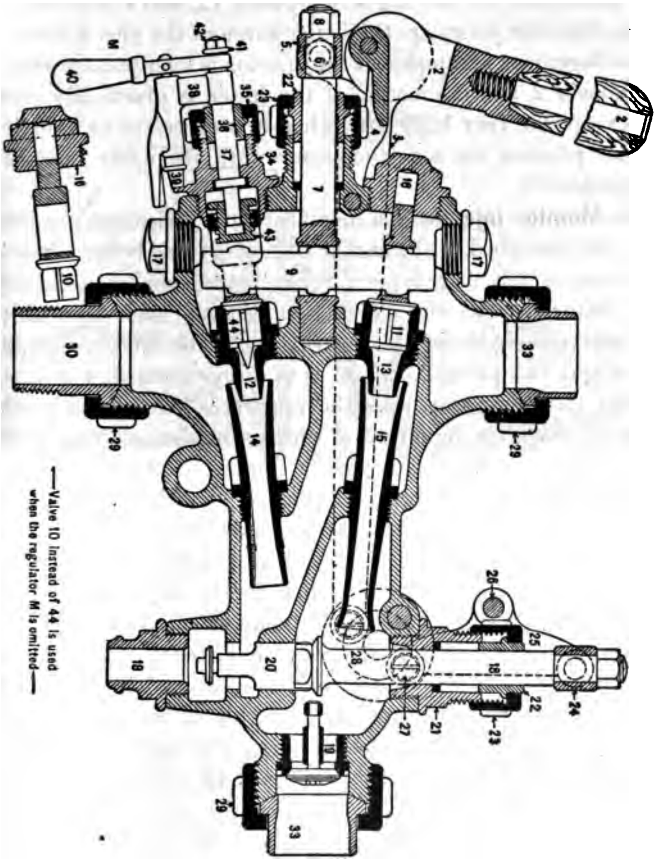


Sellers' Injector, 1887.

is, that by simply removing the end caps, all of the tubes ca removed, for examination or for cleaning, without disturbin pipe connections.

Sellers' self-acting injector of 1887 is of the double jet and, in common with other injectors of this type, it adjust maintains the proper supply of water for any pressure of st besides restarting automatically after a temporary break the disturbing cause is removed. Referring to the accompan cut, 3 is the forcing nozzle, which is placed within the li nozzle 4, these being so proportioned that a suction is maint in the feed pipe even when there is a discharge from the fo nozzle. The combining tube is shown at 2. The water whicl been lifted into this tube by the lifting jet here comes in co with the forcing jet, which imparts to it an increased velocity, the mixture rushes past the overflow openings into the deli tube, and thence into the boiler. This injector is espec designed for use on locomotives. It may be operated effici under a wide range of boiler pressures, and its capacity ma reduced to 36 per cent. of the maximum by throttling at the valve, so that it may be used to feed continuously by si adjusting the water valve to suit the requirements.

The Korting Injector, known in this country as the *Sc Injector*, which is also of the double jet type, may be used u varying pressures and for both hot and cold water. In accompanying cut, 15 and 14 are the two steam jets, the being used for lifting the water, the other to force it into boiler. It will work at the highest as well as at the lowest press because the quantity of water taken in by the first jet and d ered to the second is in proportion to the steam pressure, and operate with hot water because the first nozzle is so proporti as to insure a high suction, and as the water is delivered to the ond nozzle under pressure, the temperature may correspond to pressure without interfering with the operation of the appar The injector has no overflows in either of the combining t The operation is had by simply moving the lever 2 to th e first motion of the lever opens the lifting steam nozzle 12, ause the forcing valve 44, having a larger area, is kept closed

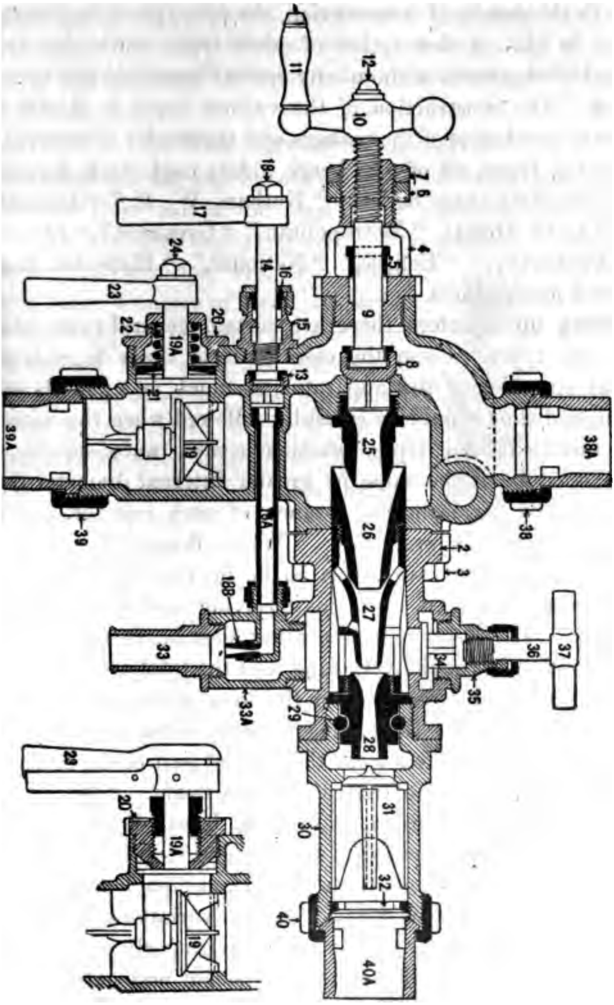


Korting Injector.

the pressure of the steam upon it and acts as a fulcrum to the 'er. *The water is now raised* and will appear at the waste-pipe *The lever is now drawn further* to the left, which closes th vertical overflow to the lifting set 15, and diverts the w through the forcing combining tube 14. A further motion of lever then opens the forcing steam nozzle 12, and closes the o flow, so that the jet enters the boiler through the check valve By this ingenious arrangement the injector is manipulated enti by the lever 2, and the motion of the latter is practically con uous except for very high lifts, when it is necessary to hold i the first position for a few moments until the water appear the overflow 18.

The Monitor injector is a modification of Friedman's Injec which was described in the earlier editions of this book. It is of the most widely used types for locomotives, and contains a novel features. The cut, which is a sectional view through apparatus, clearly shows its construction. The combining tub divided into two parts, 26, 27, so as to form an overflow in it. addition to the regular tubes the apparatus has an indepenc lifting set or ejector, by means of which a suction is created in supply pipe. In this respect it is similar to other double-t injectors, although the arrangement is slightly different. operate the injector steam is first admitted to the lifting jet 1ε by turning the handle 17. The steam discharges through overflow nozzle 33, creating a suction in the supply pipe. W water appears at the overflow the main steam jet is opened turning the handle 10, and the water is forced through the c bining tubes 26, 27, into the delivery tube 28, and thence into boiler. If the steam pressure is high, all of the water will taken away from the lifting jet and dry steam will be dischar from the overflow, which may be stopped by closing the valve by means of the handle 17. If the steam pressure is low some of the water continues to pass out of the overflow, the w supply must be throttled by means of the valve 19, whicl operated by the handle 23. In a later form of this injector *operation is performed* by means of a lever which replaces *two handles 11* and 17.

From the descriptions which have been given of various



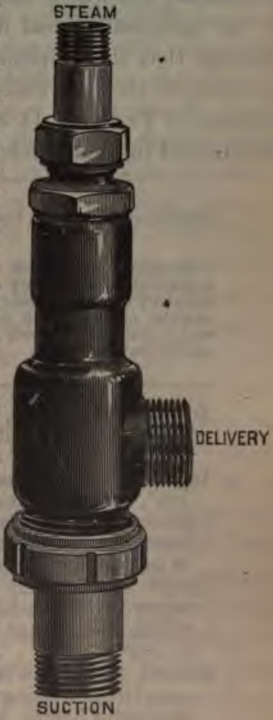
Monitor Injector.

of modern injectors, it will be evident that their differences lie entirely in the details of construction, the principle being exactly the same in all. A description of other types would involve a great deal of repetition without any special benefit to the user of this book. The construction of the various types is clearly set forth in the catalogues of the makers, and the reader is referred to the following types, all of which are widely used, both for locomotive and stationary boilers: "Nathan, W. F.," "Belfield," "Rue" (Little Giant), "Metropolitan," "Gresham," "Manhattan," "Penberthy," "Eclipse," "National," "Hancock Inspirator," and many others.

In setting up injectors there are certain general rules which apply to all types. Upon the observance of these depends the successful operation of the apparatus, as much as upon its construction, and they should be carefully followed when the injector is first installed: All pipes, whether steam, water-supply, or delivery, must be of the same or greater internal diameter than the hole in the corresponding branch of each injector, and as short and straight as practicable. When floating particles of wood or other matter are liable to be in the supply-water, a strainer must be placed over the receiving end of the water-supply pipe. The holes in this strainer must be as small as the smallest opening in the delivery-tube, and the total area of all the holes must be much greater than the area of the water-supply pipe, to compensate for the closing of some of them by deposits. The steam should be taken from the highest part of the boiler, to avoid the carrying over of water with the steam. "Dry pipes" should always be used on locomotives to insure dry steam; wet steam cuts and grooves the steam spindle and steam-nozzle. The steam should not be taken from the steam-pipe leading to an engine, unless such pipe is large. Sudden variations in pressure may break the jet. After all the pipes are properly connected to the injector and to the boiler, and before steam and water are admitted through them to the injector, they should be disconnected and well washed out by blowing steam or running water through wash out all red lead, scale, or other solids that may be in . Finally, in setting injectors it is important to place them s possible, since their capacity is reduced and the prompt- reliability of their action diminished as the height of lift is d.

The Ejector or Lifter.

nnexed cut represents the ejector or lifter, which is prac- ne lifter side of the inspirator,* with a reduced steam-jet rged lifter combining-tube. It is suitable for breweries, s, bleacheries, etc.; for trans- arge volumes of water, lye, acid, er liquids. It will deliver more any kind at a low lift, with a essure of steam, than either the or inspirator; but it is not as or as well adapted to the dif- urposes for which these instru- re used, as either of them. It a very good purpose when cellars looded in consequence of heavy , high tides, or overflowing of and requires no very intelligent nent. Its action is based on the inciple as that of the injector, nore simple, as it has no adjust- novable parts.



d of starting the ejector.—All ecessary to start the ejector is to the steam, after which it will long as the water-supply and essure continue; and it is imma- nat lift it is started on, as the pply may be gradually reduced

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nspirator is the name given by John Hancock of Boston to the *injector.*

to meet the requirements of the quantity of water to be di charged.

Pumps vs. Injectors.

Since the injector was first introduced in this country in 18 it has rapidly grown in favor. It has the distinct advantage over pump that it feeds a continuous stream of water into the boiler, be sides being more compact and having no moving parts subject wear and tear. As far as economy in the use of steam is concern it cannot be said that it is more economical than a pump under conditions, but where the temperature of the feed water is low is the more economical device of the two, and it may be said, general, that the efficiency of the injector increases as the te perature of the feed water diminishes. The following table, c culated by Professor D. S. Jacobus, gives the relative value pumps and injectors under different conditions.

Method of Supplying Feed Water to Boiler Temperature of feed water as [illegible] to the pump or to the [illegible] Fah. Rate of evap [illegible] of boiler [illegible] pounds of [illegible] pound of coal from and [illegible] Fah.	Relative amount of coal required per unit of time, the amount for a direct acting pump, feeding water at 60°, without a heater, being taken as unity.	Saving of fuel over the amount required when the boiler is fed by a direct acting pump without heater.
Direct acting pump feeding water at 60° without a heater	1.000	.0
[illegible]	.985	1.5 per ct.
[illegible]	.938	6.2 "
[illegible]	.879	12.1 "
[illegible]	.868	13.2 "

CHAPTER XIV.

FEED-WATER HEATERS, ECONOMIZERS, SEPARATORS, AND TRAPS.

Heating the feed water before it enters the boiler has three istinct advantages. In the first place, if the water enters the oiler at ordinary temperatures, which range from 70° in summer o 35° in winter, the cold water, coming in contact with the hot lates and tubes, causes strains in the boiler which will impair its fe very materially. This may be avoided almost entirely by eating the water to a temperature of about 210° before it enters he boiler. Secondly, it has been found that the corrosive effect f hot water is much less than that of cold water; besides, the heating of bad water to a high temperature removes a large proportion of the impurities, depositing them in the heater, where they re of less importance and where they may be easily removed, instead of allowing them to be carried into the boiler, where a deposit of scale is dangerous unless frequently removed. Lastly, a very material gain in economy is effected by heating the feed water. If, for example, the normal temperature of the feed-water supply is, say, 50°, and the boiler is used for making steam at, say, 80 pounds pressure it will require in all about 1162 heat units to evaporate each pound of water. Suppose the boiler has a capacity of fifty horse-power, which means that about 1500 pounds of water are evaporated, requiring $1162 \times 1500 = 1,743,000$ heat units per hour. Under the best conditions this would mean a consumption of about 175 pounds of coal per hour, assuming that of all the heat contained in each pound of coal 10,000 units are available for making steam. Now suppose the feed water enters the boiler at 210°. It will then require only 1002 heat units to evaporate a pound of water, and consequently there will be used only $1002 \times 1500 \div 10,000 = 150$ pounds of coal per hour under

Percentage of Saving in Fuel by Heating Feed-Water. Steam at 70 Pounds Gauge Pressure.

Initial Temperature Feed.	TEMPERATURE, TO WHICH FEED IS HEATED.														
	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	250°	300°
35°	5.53	6.38	7.24	8.09	8.95	9.89	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40	29.34
40°	5.12	5.97	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89	28.78
45°	4.71	5.57	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.36	14.22	15.09	18.37	28.22
50°	4.30	5.16	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87	27.67
55°	3.89	4.75	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	18.38	27.12
60°	3.47	4.34	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86	26.56
65°	3.05	3.92	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35	26.02
70°	2.62	3.50	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84	25.47
75°	2.19	3.07	3.96	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	12.95	12.84	15.33	24.92
80°	1.76	2.65	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.82	24.37
85°	1.30	2.22	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32	23.82
90°	0.89	1.78	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81	23.27
95°	0.45	1.34	2.25	3.15	4.05	4.96	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31	22.73
100°	0.00	0.90	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80	22.18

similar conditions. In other words, the heating of the feed water has saved 25 pounds, or about 15 per cent. of the fuel consumed. In this way it may be shown that about 1 per cent. of the fuel is saved for every ten degrees the temperature of the feed water is raised. The preceding table is calculated to show the exact saving in fuel for different temperatures when the steam pressure is 70 pounds.

The methods of heating feed water generally used are three in number, viz.:

Feed-water heaters, consisting of an arrangement whereby the exhaust steam* from the engines, pumps, etc., is brought in contact with a fresh supply of feed water, either directly or through the medium of a series of tubes, in such a way that the heat of the steam is imparted to the feed water until the temperature of the water is raised to from 200 to 212 degrees. After passing through the heater the steam, if not condensed in the heater, passes either into the atmosphere or into a condenser.

Economizers, consisting of an arrangement of tubes placed usually at the point where the boiler flues enter the stack. The feed water is pumped through the tubes into the boiler, and in its passage absorbs the heat of the escaping gases, which would otherwise be wasted. An economizer is essentially a water tube boiler, and as such should always be equipped with a suitable safety valve.

Condensers, being essentially the same as feed-water heaters in their mode of operation, except that there is a considerable excess of water used above that required in the boiler, the main object being the condensation of the exhaust steam rather than the heating of the feed water. (See also Condensers, page 569.)

Feed-water heaters may be divided into two principal classes: Closed heaters and open heaters.

Closed feed-water heaters consist of an arrangement of tubes

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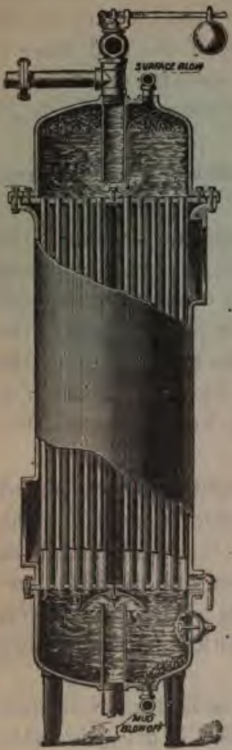
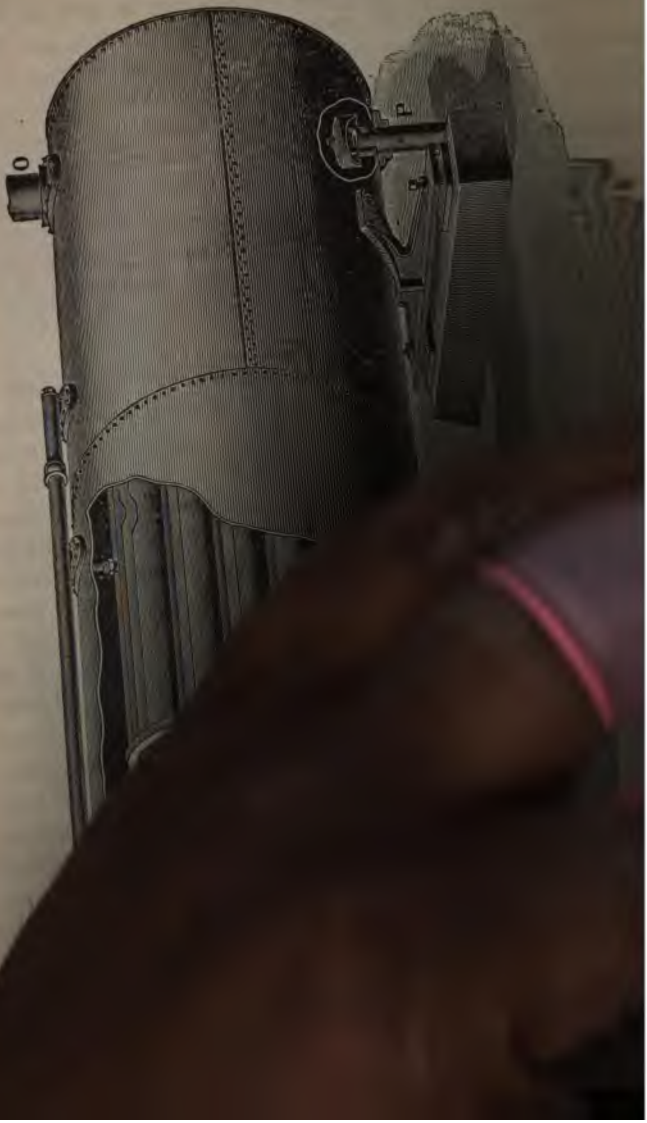
* In some cases where the water contains a large percentage of solid matter in solution, live-steam feed-water heaters are also used.

through which the feed water is forced into the boiler, the
being surrounded by the exhaust
from the engine. They have the a
tage over open heaters in this: th
water passes through the pump col
pump being placed between the sou
supply and the heater. There is a
more or less difficulty in pumpin
water, and if the heater cannot be p
higher than the pump the closed ty
preferable. On the other hand, i
properly constructed, closed heaters
cause a back pressure on the en
which will lose more power th
gained by raising the temperature o
water. Besides this, many of the
which are in common use are very
cult to clean. This is an importan
sideration in the selection of a heate
cause there is always a precipitati
lime if any is present in the water
the removal of this and other de
should be provided for. The a
panying cut illustrates the Goubert
of heater, which belongs to this
The tubes are expanded into tube
at either end of the heater. A
pressure is within the tubes, there is little danger of their
lapsing, and they are made of brass in order that they will
ily conduct the heat from the steam to the water. This h
has the great advantage over many others of the same class,
the tubes are easily accessible for cleaning, it being merely
sary to remove the head. The cross section of the steam pas
is from eight to sixteen times as great as that of the exhaust
that no back pressure can ensue from its use. Referring



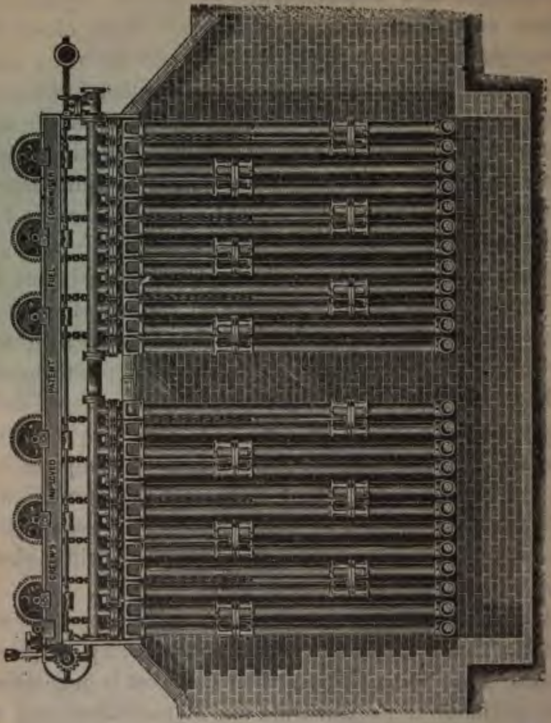
ither the top or bottom side opening may be used as the ex- inlet or outlet. The water enters at the bottom and leaves top. In the Berryman heater, which also belongs to this the tubes are ∩ shaped, both ends of the tube being ex- d into the same tube sheet. By this method of construction eater may be made much shorter and the tubes are not ed by expansion and contraction. The National Heater ts of a spiral coil or coils of brass tubing enclosed in an iron This has the advantage that there are no joints to become and the whole arrangement is exempt from strains due to sion and contraction. Both of these types, however, are hat more difficult to clean.

en Heaters.—In the open type of feed-water heaters the supply must be under pressure, as it is not possible in this o force the water through the heater. Moreover, the heater be placed above the pump, otherwise the hot water will not the pump plunger, as already explained. The cut repre- the well-known Hoppes feed-water heater and purifier, is one of the oldest of this class. It consists of a series of pans enclosed in a cylindrical shell made of steel plate, at either end by cast-iron plates. The front head is able to permit the pans to be taken out for the purpose of ing. The exhaust steam enters at the back end, and after g through an oil catcher it enters the heater proper and at the front through the pipe *O*. The pipe *S* is a drip the oil catcher. The water is admitted at the top, the sup- eing regulated by the valve *T* and float shown at the bottom heater. After filling the top pan the water overflows and ght in the next pan, and so on until it reaches the bottom, it leaves through the pipe *P*, which connects with the feed- When the plant is in operation the pans are always with water and completely surrounded by the exhaust In this way the water is heated to the highest attainable rature, while the pans afford a settling chamber for the mpurities, which may be easily removed from time to time.

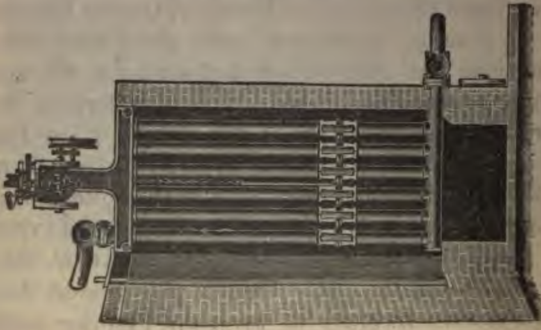

O
P

The advantages and disadvantages of the two types of feedwater heaters may be summarized as follows: With closed heaters the water passes through the pump cold, and the water supply, pump, and heater may be placed in any convenient position relative to each other, while in open heaters the level of the source of water supply must be above that of the heater, and that of the heater above that of the pump. Further, the feed water entering the boiler where the closed heater is used is fresh water, and does not contain any of the impurities absorbed in the passage of the steam through the engine. While it is claimed that these mpurities are removed in open heaters by the use of oil separators, etc., yet there is a strong probability that a sufficient quantity remains to injure the boiler plates to some extent. On the other hand, the back pressure on the engine in the case of open heaters s practically nothing, while in closed heaters it is often quite appreciable, the purification of the water is more complete in the open type, and the efficiency—that is, the temperature to which he water is raised—is usually higher. Besides, the open heater is not required to operate under pressure; it is consequently cheaper o build and is less liable to accident.

Economizers, though not used as extensively as feed-water heaters, without doubt frequently add to the economy of operation n large plants, while in small ones their first cost is generally too great. The sectional views illustrate one of the oldest and most widely used types of this apparatus, known as Green's Economizer. It consists of a series of cast-iron tubes about four inches in diameter and nine feet long, connected at the top and bottom by headers similar to those used in some types of water-tube boilers. The headers are also connected by two branch pipes running engthwise outside of the brickwork. The feed water enters the apparatus through the connection shown at the bottom, which is n the end of the lower branch pipe nearest the point of exit of the gases, and leaves it through the connection shown at the top, which is *in the end of the upper* branch pipe nearest the point *where the gases enter. In order* to keep the exterior surfaces of

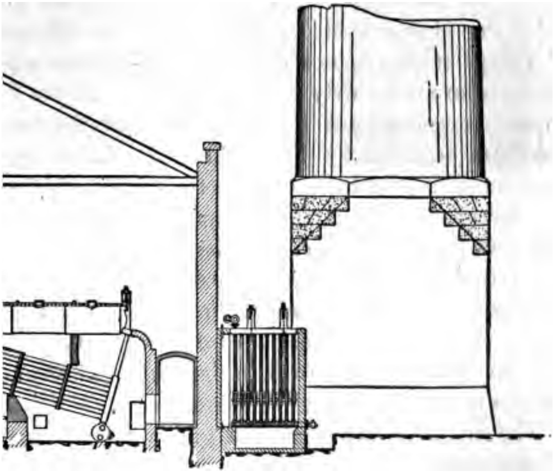


Longitudinal Section through Economizer Chamber.



Cross Section through Economizer Chamber.

from soot it has been found necessary to devise an or scraping the tubes continually. This is also ıuts, and consists merely of a series of scrapers surtubes, which continually travel up and down, the ing the mechanism being supplied either by belting nient shaft or by an independent engine or motor. ıted, the apparatus should be fitted with a safety quite possible for the pressure in the tubes to become gh. It should also be fitted with a blow-off pipe, set in such a way as to be readily accessible for the t. The following cut shows a convenient method



ıd setting the economizer, being the arrangement ı power house of the Union Railroad Company of I.

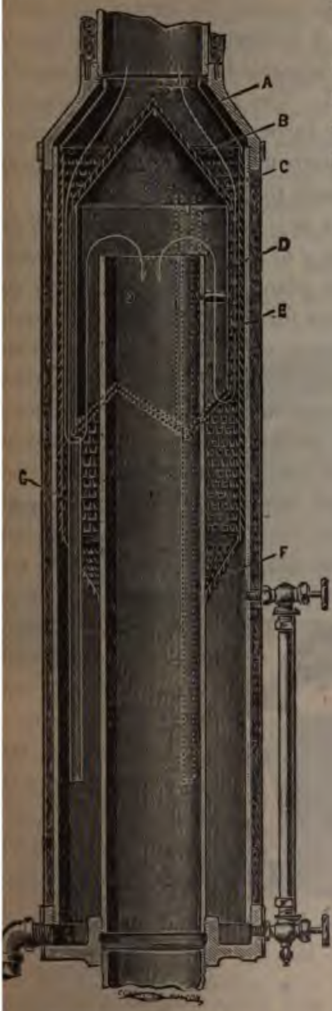
though a comparatively recent addition to the list ınces, are now recognized as an important and suct to steam-power plants. The function of a sepa*ove from vapors and* gases the liquids and solids *y along with them.* Thus a live-steam separator

is intended mainly to remove the entrained water from the s
while a separator placed in the exhaust piping when the ex
steam is to be condensed and used again in the boilers, is inte
to remove the grease which it has accumulated in its pa
through the engine. The use of dry steam in engines is in
tant not only because an accumulation of water in the cylinc
a menace to its safety, but also because entrained water inv
a very considerable reduction in the economy of operation.
water carried into the steam cylinder not only carries away
from the boiler which is incapable of doing any work in
engine, but it also materially increases the initial condensa
one of the most important losses of power in the engine. H
there should be provided some device which will insure dry ste

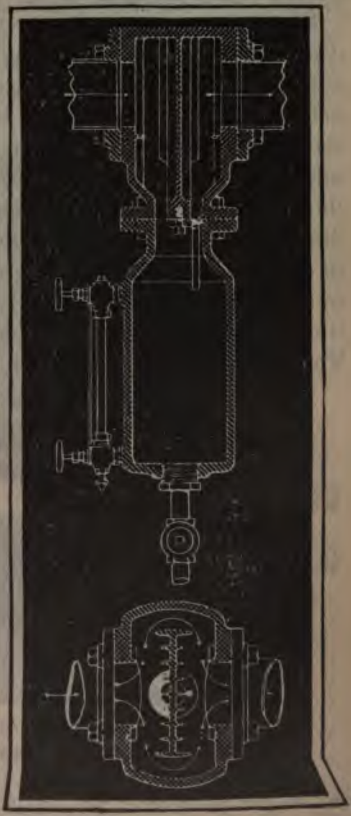
The principles upon which the action of steam separators sho
be based are now fairly well understood. In the first place, t
should be constructed in such a way that the momentum wh
has been acquired by the liquids and solids is destroyed. T
is accomplished by baffle or deflecting plates, which alter or reve
the direction of flow of the steam, or by allowing it to exp
and give the heavier particles time to fall by the action of grav
After this has been accomplished it is important to prevent
separated water from being again picked up and carried along
the purified gases. Finally, care must be taken that an am
and easy passage is afforded to the current of steam, so that th
will be no loss of energy from friction.

The cuts on p. 283 represent in section two well-known ty
[illegible] in which these principles are embodied, Sweet's
[illegible] The former is for use in a vertical pipe and is
[illegible] engine cylinder, while the latte
[illegible] both can be slightly m
[illegible] horizontal or vertical pi
[illegible] Sweet's separator, the course of
[illegible] apparatus is indicated by
[illegible] merits are that the water
[illegible] contact with and hence c

picked up by the current of steam and the so-called "whip-snapping" action or sudden reversal of direction of flow of the steam, by which the rest of the moisture is shaken out, as it were. In Cochrane's separator the separation is effected by a



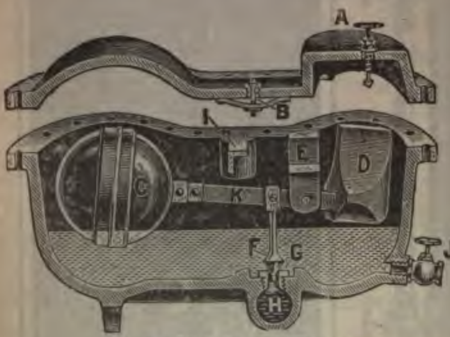
Sweet's Separator.



Cochrane's Separator.

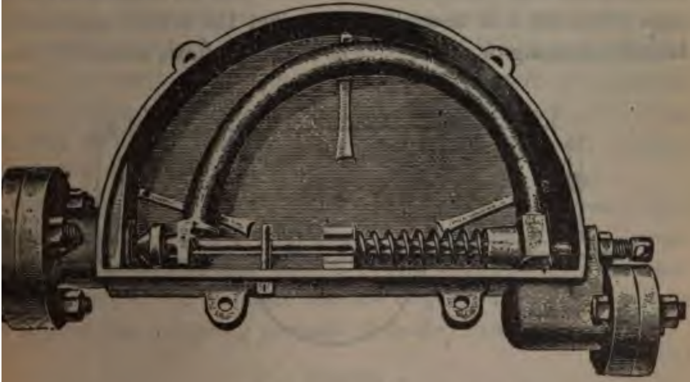
ribbed baffle plate placed between the steam inlet and outle The sides of the separator converge toward the centre and lead t the reservoir, the mouth of which is protected, so that the purifie steam will not again pick up the separated particles during thei descent or after reaching the well. The apparatus is so designe that the area of the steam passage through it greatly exceeds th area of the steam pipe, thus minimizing the loss in friction an giving the heavier particles a chance to fall to the bottom.

Steam traps are used wherever it is necessary to carry off cor densed steam without allowing any of the steam itself to escap with it. There is hardly a steam plant in existence which doe not contain one or more steam traps for collecting and dischargin the condensation in the steam pipes, separators, etc., and it ma safely be said that the steam trap is one of the most important o the accessory devices in a modern steam plant. The number o different types of traps which the market offers and the differenc in their mode of action are so great that it would be impossible her to attempt to describe them all, but the two cuts given below wi illustrate, in a general way, how the desired result is attaine The McDaniel trap is one of the oldest and most widely use types in existenc The cut illustrat the trap in longitu dinal section, wit the cover remove It consists of a cas iron casing into th top of which leads pipe (not show from the syste which is to b drained. The wat of condensation co *lects in the bottom* of the casing, and when its level is sufficientl *high, it acts upon* the copper float C, which, with the aid



McDaniel Steam Trap.

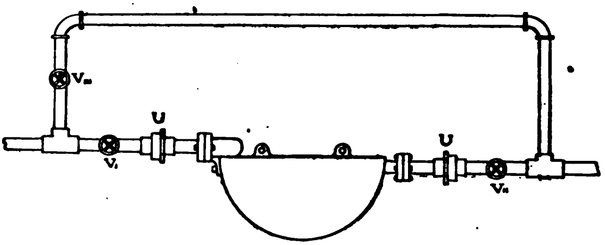
em of levers, *K*, and a counterpoise *D*, actuates the plug valve ifting it from its seat *G*, when the water in the trap is high, closing it when the water is low. As will be seen from the the cover is removable, so that the trap is accessible for cleanand repairs. There is also provided a blow-off pipe *J*, which be connected to the waste pipe. The set screw *A* in the er is for the purpose of adjusting the rate of discharge. It is med for the McDaniel trap that it will discharge continuously without allowing any steam to escape with the condensation. ien properly adjusted there is no reason why it should not subitiate these claims, and it has been found a very satisfactory p for both high and low pressures. The Heintz steam trap,



Heintz Steam Trap.

ustrated in the other cut, is entirely different in its action, but complishes the same object, viz., the continuous discharge of e condensation without wasting steam. It consists of an outer sing with removable cover, a curved tube spring of elliptical oss section, a plug valve, and a spiral spring. The tube spring partially filled with a liquid which, heated by the condensed ater surrounding it, completely fills the tube when the temperare reaches 197° F. The action is similar to that in the Bourdon pressure gauge, for as the temperature of the water rises, press is exerted within the tube, causing it to straighten out and t close the plug valve. When the temperature has reached 21 the valve is forced tightly against its seat, remaining so u enough condensation has accumulated to lower the temperat one degree, when the valve opens sufficiently to pass off the c densed steam, but closes again as soon as the water is discharg The opening and closing are accomplished so quickly that there practically a continuous flow of water from the outlet.

By-Passes.—All of the appliances which have been describ in this chapter should be provided with by-passes—that is, th should be connected with the piping in such a way that eit the steam or the water can be made to pass through an auxili pipe whenever it is desirable to cut out the heater, separator, trap for cleaning or repairs. The diagram shows how a by-pass



usually arranged. It consists of a pipe passing around the ap ance to which it is connected, and three valves $V_{/}$, $V_{//}$, and Under ordinary conditions the valves $V_{/}$ and $V_{//}$ remain open a $V_{///}$ is closed. But if the by-pass is to be used, the valve $V_{///}$ opened and $V_{/}$ and $V_{//}$ are closed. The heater or other applia may then be disconnected by means of the unions U, without int fering in any way with the continuity of operation.

CHAPTER XV.

FURNACES, GRATES, CHIMNEYS, ETC.

Furnaces and Flues.—The rules which apply to the strength 'the cylinder subjected to a pressure from within, such as cylin-ical boilers, do not apply to furnaces and flues, where the essure is exerted from without. The thickness of a cylinder bjected to a given pressure from within depends only upon the iameter of the cylinder, the pressure, and the strength of the aterial. The tendency of the internal pressure is to keep the lindrical shape intact, so that rupture will occur only when e material of which it is made gives way. When, however, the ressure is exerted from without the case is more complicated, ecause unless the cylinder is mathematically perfect, any devia-on will be exaggerated by the pressure, so that it will collapse ng before the crushing strength is reached.

The experiments of Fairbairn, made some forty years ago, owed that the strength of cylinders subjected to external press-re varies directly as the square of the thickness of the metal, nd inversely as the diameter and the length. Rankine's formula r finding the collapsing pressure of boiler flues is:

$$P = 806000\,\frac{t^2}{l\,d}$$

here $P =$ collapsing pressure in pounds per square inch.

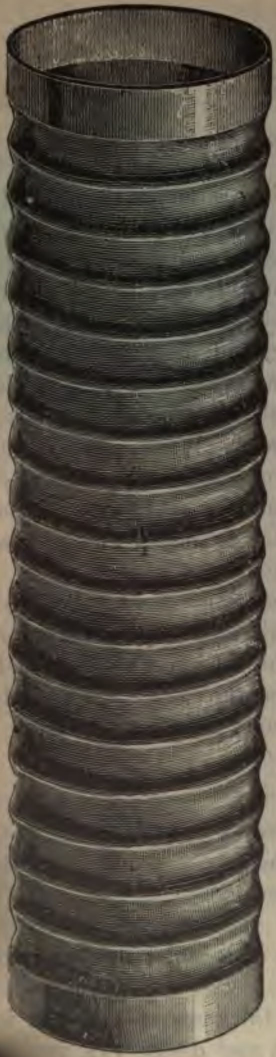
$t =$ thickness of the iron in inches.

$d =$ diameter of the flue in inches.

$l =$ length " " feet.

Ience, to find the collapsing pressure of a boiler flue, we have he following:

Rule.—Multiply the square of the thickness of the iron in nches by *the constant number 806000*, and divide this product *y the product of the diameter* of the flue in inches and its



Morrison's Suspension Furnace.

length in feet. The quotier be the collapsing pressu pounds per square inch.

Example.—What pressur square inch will cause a flue 24 inches in diameter ar feet long to collapse, if the is $\frac{3}{8}$ of an inch thick?

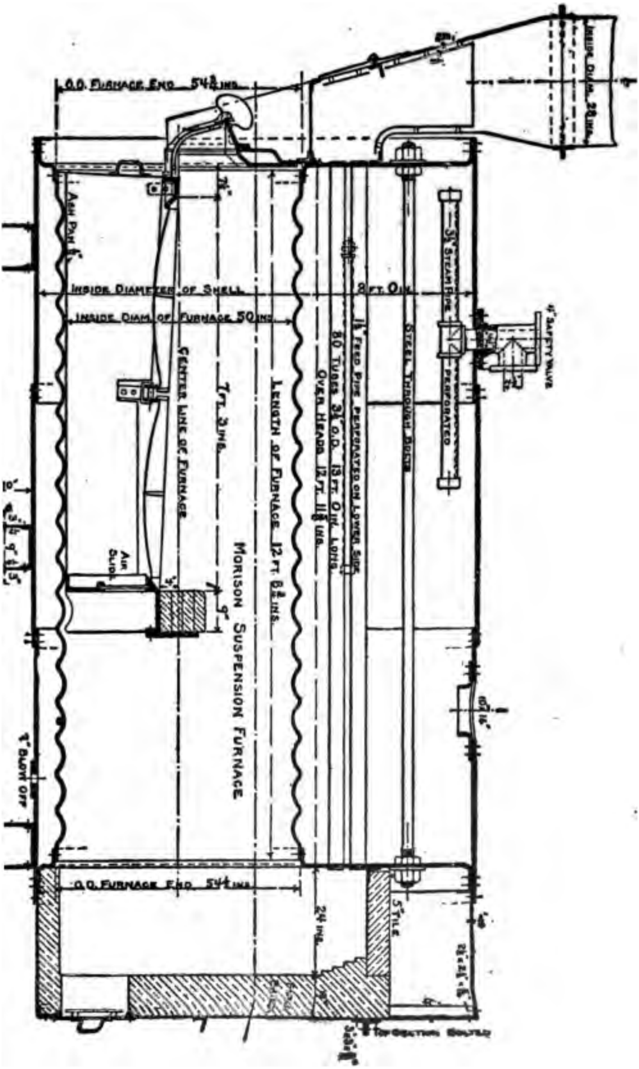
Collapsing pressure

$$=\frac{806000\times.375\times.375}{24\times20}$$

$= 236$ pounds.

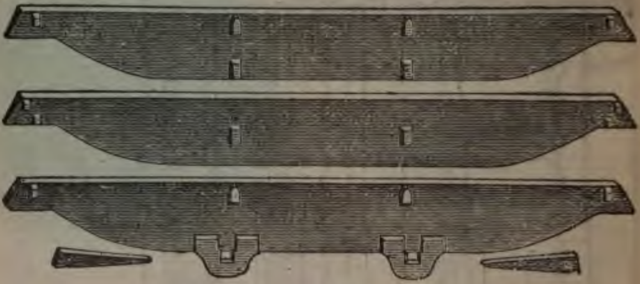
Various methods have employed for strengthening flues, such as angles and tee eted around the inner or surface at intervals. In such the strength is to be calculat the above rule, but the len taken as the distance betwee stiffening rings. Galloway (see Galloway Boiler, p. 162) also been employed to increa strength of flues. The mos cessful plan, however, is th vised by Mr. Samson Fo Leeds, England, which c of corrugating the flue, as in the perspective and sec views of Morrison's susp furnace. This plan of corru the furnaces and flues is n most universally used with nally fired boilers. Beside

reased strength of this type of furnaces over plain cyli

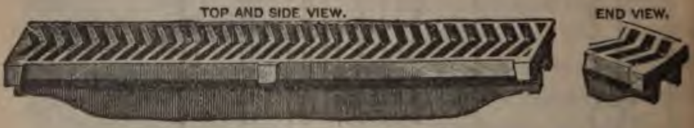

O.D. FURNACE END 54½ INS.
INSIDE DIAM. 28 INS.
ASH PAN
INSIDE DIAMETER OF SHELL 8 FT. 0 IN.
INSIDE DIAM. OF FURNACE 50 INS.
CENTER LINE OF FURNACE
7 FT. 3 INS.
LENGTH OF FURNACE 12 FT. 8½ INS.
MORISON SUSPENSION FURNACE
1½" FEED PIPE PERFORATED ON LOWER SIDE
80 TUBES 3¼" O.D. 13 FT. 0 IN. LONG
OVER HEADS 12 FT. 11⅝ INS.
STEEL THROUGH BOLT
3½" STEAM PIPE PERFORATED
4" SAFETY VALVE
AIR SLIDE
1" BLOW OFF
O.D. FURNACE END 54¼ INS.
24 INS.
5" TILE
TOP SECTION BOLTED

furnaces, it offers the additional advantages of greater heating surface and greater elasticity. The longitudinal sectional elevation shows how the furnaces are attached.

Grates ordinarily consist of a number of cast-iron bars supported at the ends on wrought-iron bearers. The shapes given to these bars are various, depending mainly upon the character of the fuel to be used. It would be impossible to give, within the limits of this book, any conception of all that has been evolved in the way of grate bars, but a few of the well-known types manufactured by Horace E. Frick, of Philadelphia, are illustrated in the following cuts, which are self-explanatory. In general it may be said that the bars should be girder-shaped for strength, long grates being usually made in several pieces with bearers between the different lengths, as shown in the longitudinal sectional elevation of Morrison's suspension furnace, p. 289. The grates are set with a considerable slope toward the bridge wall to facilitate th

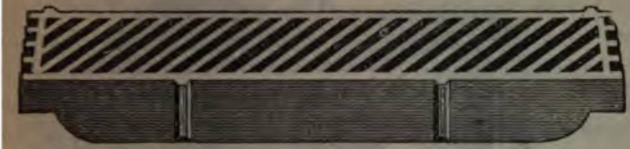


The Interlocking Grate Bar.



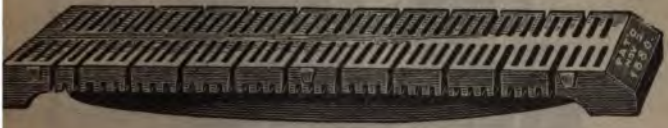
Rogers' Patent Grate.

ribution of fuel. The spacing of grate bars depends entirely n the nature of the coal which is to be burned. The air space



Obtuse Angle.

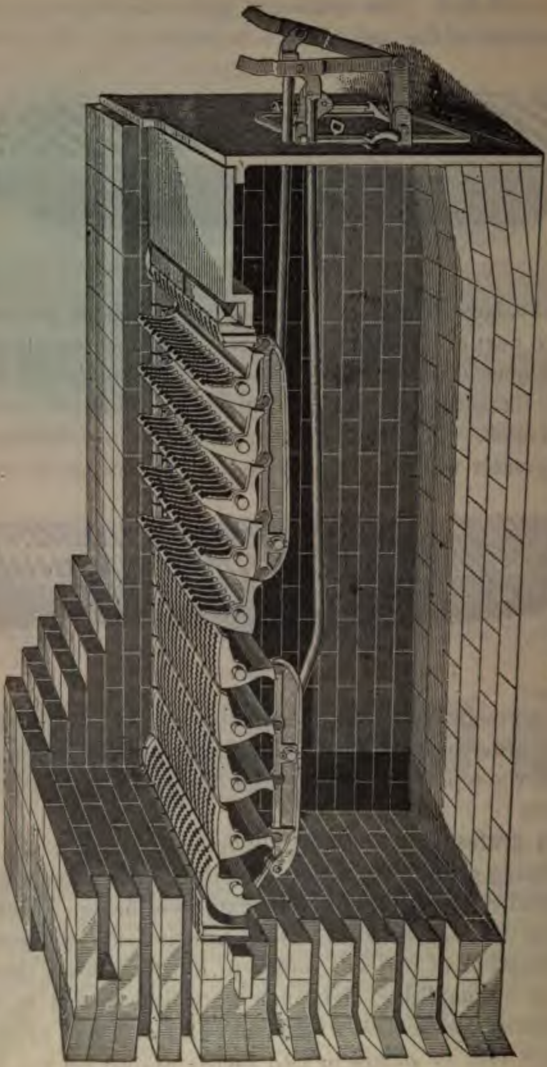
veen the bars should be subdivided as much as possible, so every part of the fire will receive its proper supply of air. bituminous coal the spaces between the bars should be ½-⅝ ; but for anthracite, especially the finer grades, it should be over ⅜ inch. Of course, the smaller the spaces between the , the greater will be the resistance to the passage of air, and



The Improved Keystone Grate.

fine anthracite fuel it is frequently necessary to use forced ught in order to make the combustion sufficiently rapid. The ance of the top of the grates from the ashpit varies from 24 0 inches.

haking grates, and crushing, dumping, rocking, water circung, rotating grates, etc., are names given to various designs of tes intended to facilitate the operations of firing. There are ny types, differing to some extent in their mode of operation, a description of one will suffice to illustrate what they are ended to accomplish. McClave's grate is intended to shake fire, *remove clinkers from* soft-coal fires and fine ashes from *l-coal fires, etc., by means of* two levers placed on the outside,



McClave's Improved Grate.

ich are operated without opening the furnace doors. The cut
ows the two sections of the grate in their extreme positions,
m which the method of operating will be made sufficiently
ar. The McClave grates are made with different sizes of meshes
suit different kinds of fuel, and they are so designed that the
aking movement does not increase the size of the openings. The
ate is divided into halves, each half being operated by a separate
ver, so that the clinkers may be removed without wasting the
nconsumed fuel, which is shoved on the stationary half while the
inkers and ashes are cut through on the other.

Automatic Firing.

Automatic or mechanical stokers consist of a mechanism
ttached to the boiler by means of which the firing—that is, the
eeding of the fuel to and the removal of the ashes from the furace—is performed mechanically. The first mechanical stokers
ate back to the time of James Watt, but it is only within the
ast few years that they have been used to any great extent. In
eneral it may be said of these devices that for small steam
lants they are too expensive and the saving too small to warrant
heir installation, but for large plants they offer important advanages: fuel economy, prevention of smoke, saving in labor, and great
leanliness in the boiler room. Hand firing, even under the best
onditions, occurs at irregular intervals, and usually more coal is
ut on than is necessary. It is not usually expected of a fireman
hat he shall exercise any special ability in performing his duties.
And yet the results obtained depend largely upon the fireman, for
f he will not spread the coal evenly over the grate and at a nearly
uniform rate, the effect will soon be noticeable in the coal consumption. With mechanical stokers the firing becomes entirely
independent of the skill or the efforts of the fireman, the fuel
being mechanically spread over the grate at a uniform rate and
allowed to remain there just long enough to be consumed. Consequently *the combustion is complete*, and very little unconsumed
arbon passes out of the chimney, even though a poor grade of

coal may be used. The labor of firing is cut down very materially, there being no cleaning of fires and no manual labor whatever, except, perhaps, in bringing the coal into the hoppers in front of the boilers, which can also be accomplished by the aid of suitable machinery. Finally, where mechanical stoking is employed, the whole boiler plant is very much cleaner, and the man in charge can keep it so with as little labor as an engineer can the engine-room.

One of the most successful systems of mechanical stoking which has thus far been designed is the Wilkinson system, buil by the Wilkinson Manufacturing Company, of Bridgeport, Pa. There are many other* systems which have also proved successful, but a description of the Wilkinson Device will suffice to show in a general way how mechanical firing is accomplished.

The Wilkinson Automatic Stoker, as used at the Baldwi Locomotive Works, and the method of handling the coal and ashes, are illustrated in the following cuts.

The first illustration represents the interior of the boiler room on the second floor, showing the fronts of the Babcock & Wilcox water tube boilers equipped with automatic stoking apparatu (Wilkinson system). There are four batteries of two boilers each, aggregating 2000 horse-power.

The second illustration shows the exterior of the power house It will be seen that the siding has a number of holes between th tracks provided with cover plates. These holes are the entrance into the coal vaults under the boiler house. During the oper tion of the boilers an endless chain with buckets passes along th front of the coal bins, up through a cylinder at one end of th building, then over the top of the hoppers shown above the fro of the boilers, where, by a simple device, the buckets are tilte so they can be emptied into any one of the hoppers. After di charging their contents the buckets pass down a similar cylind

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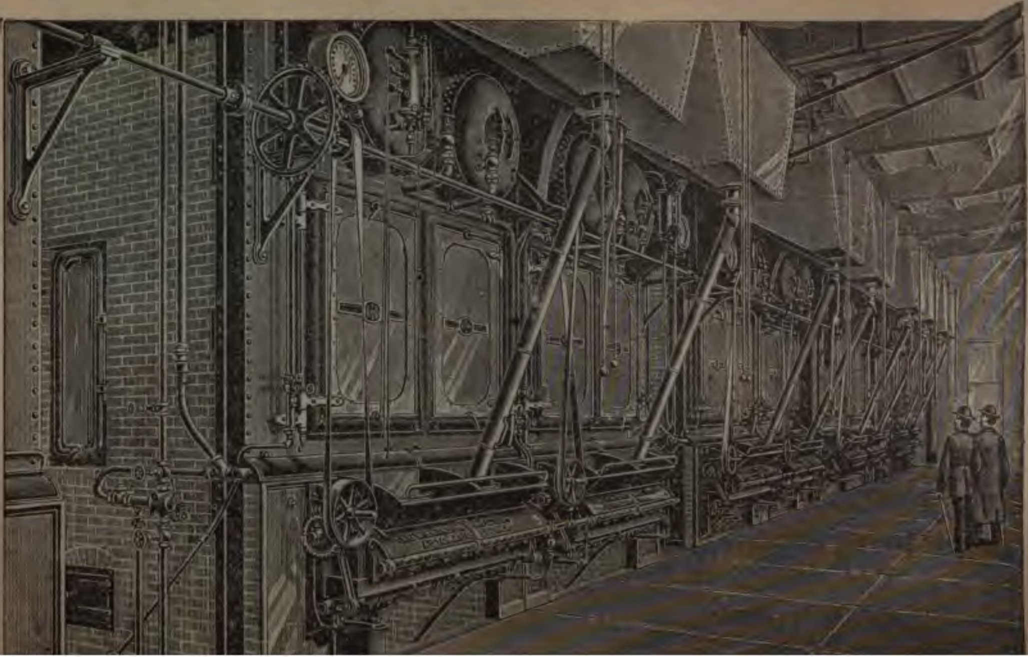
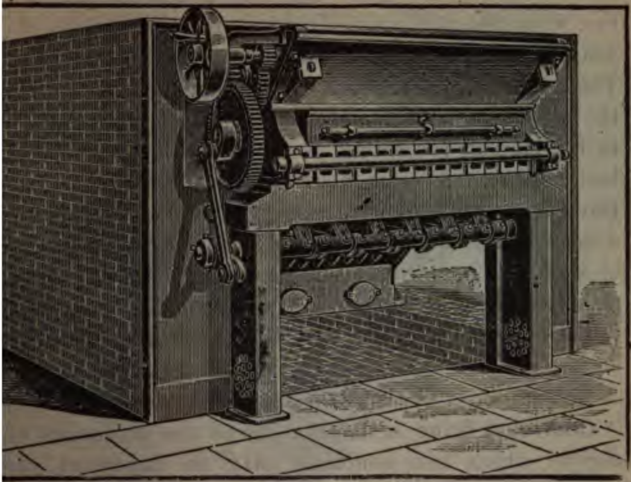
* Among the other American systems of mechanical firing the followi *may be mentioned* : Roney, Babcock & Wilcox, Murphy, American, Jon etc.

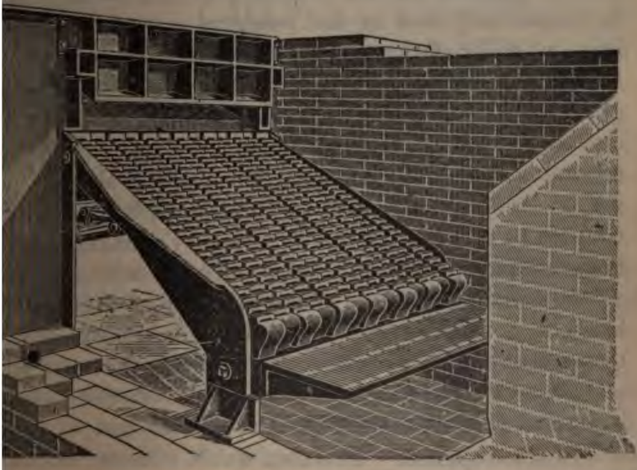


at the other end. The coal then drops down through the pipes, which are suspended by a ball-and-socket joint from the hopper. This hoisting mechanism is operated by means of a five horse-power vertical engine, not shown in the illustration. Another similar engine operates the horizontal shaft shown in front of the boilers, and this is belted to the grate-bar mechanism, by which the coal is worked along to the end of the oblique grate, and is so adjusted as to speed that complete combustion of the fuel takes place by the time it reaches the end of the grate. The grate-bar mechanism is more clearly shown in the two cuts on p. 297. The grate bars are of cast iron, hollowed and nearly triangular in cross section, the upper end being open to the blast pipe as shown in the front view, while the lower end is supported on a cast-iron box. The coal is fed by the motion of the grate, which is communicated to it from the horizontal shaft over the boilers, referred *to above*, by means of the pulley gear wheel and toggle joint *shown in the* front view. In this way the continuous back and

Exterior of Boiler Room, Baldwin Locomotive Works.



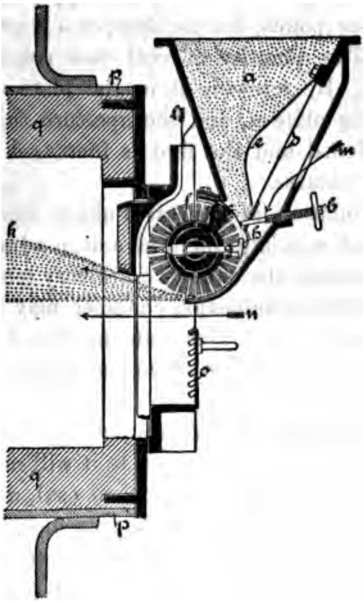
Wilkinson Stoker, front view.



Wilkinson Stoker, interior view.

forth motion of the grate bars maintains a uniform thicknes fire, while the coal gradually descends to the bottom of the gr when it falls on the stationary grate shown in the furnace v The ashes are pushed from the stationary grate by the motio the grate bars, and descend through chutes under the boiler f to the cars on the siding, as shown in the exterior view of boiler house. A steam blast is used to induce a current of through the grate, the intensity of the current being regulate a suitable valve. The amount of steam required for this pur is about 10 per cent. of that generated by the boilers. I claimed that, as the steam is decomposed by the heat of the the combustion chamber is filled with burning gases, resultin a more uniform distribution of the heating surface of the bo A further object of the steam blast is to preserve the grate ba

Coal-dust firing is another one of the inventions of the decade which will doubtless play an important part in advancement of industrial enterprise. It is hardly necessary to point out the advantages of a system of firing by which dust, or particles too fine for use with any form of grate, be economically used as fuel. Several systems for utilizing dust in boiler furnaces have been devised, and of these *Schwartzkopf System* has been most successful in consuming grade of fuel, not only economically, but also with an e absence of smoke. The cut below represents this system. apparatus consists of a hopper, *a*, filled with coal dust. The per is closed at the bottom by an elastic plate, *c*, which ca adjusted by means of a set screw, *b*, and by a shaking lid, *d*. A tionary plate, *e*, relieves the lid, *a*, of the pressure of the coal d *f* is a round brush made of flat steel wires. Attached to it hammer, *g*, which at each revolution strikes the piece *h*, fast to the shaking lid *d*. Each stroke of the hammer throws plate *d* back a certain distance, the range of which can be lated, and permits a fixed quantity of coal dust to fall thr t *thus* opened. This slot, which extends the whole w evolving brush, allows the coal to fall within reach istles, which throw it with some force into the combustion r *k*. As soon as the hammer *g* has passed the piece *h*, the springs back by its own tension and closes the aperture which the coal fell, thus checking the feed. As the arrying the hammer *g* revolves rapidly, it causes a con- and uniform feeding of the coal dust, which can, however,



lated by the screw *b*. Even damp coal and larger parti- ich may have gotten into the hopper by accident are fed and thrown into the combustion chamber, a feature s not possessed by any other system of dust firing.

combustion chamber *k* may be made in the flue of a boiler g it for a distance of five or ten feet with firebricks.

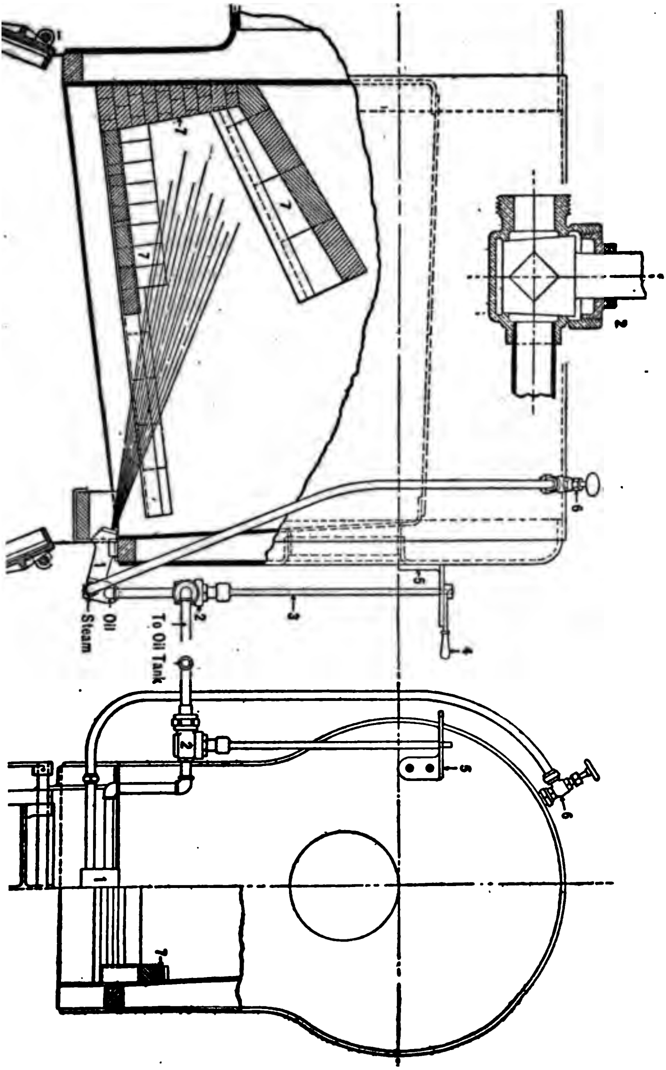
art the coal-dust fire it is necessary to build a small wood *to burn some greasy* waste in the combustion chamber

The dust being sprayed through the flame, catches fire and soon heats the firebrick lining to a point at which it tain continuous and complete combustion. In boilers wh not used during the night a fire can be started in five the firebricks having reached a bright-red heat in this tim

The air required for combustion enters at *l*, *n*, and *o*, and the lines indicated by the arrows. The supply of air can lated at all three points, but the damper *o* is quite suffic this purpose. The quantity of coal dust required is re by the screw *b*. By screwing it in, the plate *c* is presse from the shaking plate *d*, and the aperture through wh coal falls is widened and the feed is increased. By scr out the reverse obtains.

The whole regulation, as was stated above, consists in a the screw *b*, which regulates the feed, and in admitting th amount of air through the damper *o*. Every ten hours th which collects in the combustion chamber may be remo a hoe through the door *n*. One man can attend twelve b more. The power required to drive the brush *f* does no $\frac{1}{10}$ horse-power.

The use of oil as fuel has of late years grown in favo an extent that a few words in regard to it will not be ami advantages of oil over solid fuels, such as coal, wood, and are briefly as follows: The firing is extremely simple, r no other labor than the turning of a valve, so that one take care of the firing of upward of 1000 horse-power difficulty; the fire is much more uniform and more easi lated to adjust the output of the boiler to the varying co of load; the economy is much greater, because there is no and closing of the furnace door, and it is claimed that a ration of eighteen pounds of water per pound of petrol easily be attained; the firing is much cleaner and, it is safer, because of the entire absence of sparks and cind *there are* no ashes to remove; for locomotives and ste *the small* space occupied by oil as compared to coal, th


Steam
Oil
To Oil Tank

being only one-half and the space occupied one-third for the sa calorific effect; and finally the saving of space in the constructi of the boiler, oil fuel requiring a much smaller fire chamber. the World's Columbian Exposition, at Chicago, 1893, the ent boiler plant was fired with crude oil. During five months 31,0 tons were consumed, and it is stated in the official report that t consumption was about 2.1 pounds per horse-power. The meth of burning oil, as used by the Baldwin Locomotive Works, is ill trated in the cut on the preceding page, showing a longitudi section and end view of the furnace. The oil is injected throu an oil injector, 1, which is connected by means of pipes to the tank and to the steam space in the boiler. By turning on t steam by means of the valve 6, and the oil by the cock 2, whi is operated by the handle 4, the oil can be sprayed into the f nace, 7, at any desired rate. The furnace is lined with firebri and the fire can be regulated, started, or stopped instantly. quadrant, 5, shows the amount of opening of the cock 2.

Chimneys and Stacks.

The presence of draught in any locality is due, to a certain tent, to the unbalanced pressure of the atmosphere, and is, many cases, intensified and heightened by natural causes, l more frequently by mechanical and artificial arrangements. T natural draught or rush of air up chimneys or funnels is caused the buoyancy both of the rarefied atmosphere and of the ga which pass through the fuel, as well as by the natural affinity the colder and denser atmosphere to rush in and fill up the vacu caused by the escape or ascension of the preceding volume. . the phenomena connected with draught are not as well underst as they should be, considering its importance as an agent in promotion and maintenance of the combustion of fuel; the obj of draught being to supply oxygen to the burning fuel, and disse nate or eject the products of combustion.

Numerous attempts have been made at different times to n rules for the area and height of chimneys that would pr nt draught for the consumption of a certain quantity of a given time, but such formulæ have more frequently failed, ıcceeded, in giving satisfactory results, which is due probɔ the want of knowledge of the requirements in each inal case, and of the location and surroundings. Attempts many instances, made to produce a good draught by carry› chimney above all surrounding objects and buildings, but it ntly occurs that shorter chimneys of the same area and ıl dimensions have a better draught. It is claimed by some ers that chimneys ought to increase in area from bottom to be capable of producing a good draught, while others assert ıe reverse, and claim that they ought to decrease from bottom It has been found by experiment that both arrangements :ed a good draught under some circumstances, but neither n under all circumstances. The area of any chimney should ;e slightly from bottom to top, in order to provide for the ;ed volume of the heated air and gases resulting from their ;ion. It has been found that round flues produced a better ıt, as a general thing, than either square or oval ones of the ırea and height. This doubtless arises from the fact that shing through or up a flue or funnel, has a tendency to as- ;he form of a screw, which is due probably to some natural

erse currents and capping winds frequently interfere with the ıt in short chimneys, but the same effect is frequently pro- on tall ones during some kinds of weather and at certain s of the year; certain it is, that very tall stacks do not pro- corresponding draught in proportion to the height, and it en demonstrated by observation that there is nothing to be by raising chimneys very high. It often occurs that chim- ›f apparently sufficient height are incapable of producing ;nt draught. This, in many instances, arises from the fact ıe quantity of fuel consumed in the furnace will not produce ;nt *heat in the flue to rarefy* the air and cause draught, *ı other chimneys of ample* height and area, in consequence of the air and heated gases having to pass through a long, flue between the boiler and chimney, the draught is sluggish unsatisfactory.

The theory which underlies the proportioning of chimneys be briefly explained as follows: Each pound of coal consume the furnace requires about 24 pounds of air for its complete c bustion, and as a pound of air has a volume of 12½ cubic feet 32°, and the volume of the products of combustion is practic the same as that of the air supplied, the total volume of nace gases at 32° will be 24 × 12½ = 300 cubic feet. At other temperature the volume is increased in the proportion the absolute temperatures. Thus, if the temperature in the nace is 2000°, the volume of the gases will be

$$300 \times \frac{2000 + 460}{32 + 460} = 1495 \text{ cubic feet.*}$$

The draught of the chimney depends only upon the differe between the weight of a column of outside air having a hei equal to that of the chimney above the grate and that of column of hot air within the chimney. It is proportional nea to the product of the height of the chimney into the difference temperature of the outside and inside temperatures. For exam the weight of a column of gas 1 foot square and 150 feet high 32° would be:

$$\frac{1 \times 150}{12.5} = 12 \text{ pounds,}$$

while if the temperature is 500°, the weight of an equal colu will be

$$\frac{12\,(32 + 460)}{500 + 460} = 6.15 \text{ pounds.}$$

Hence, if the temperature of the outside air is 32° and that wi the chimney 500°, the difference in weight of two equal colu gas 1 foot square and 150 feet high, at those temperature

---

he *absolute* temperature is obtained by adding 460 to the Fahren to *the* Centigrade temperature.

— 6.15 = 5.85 pounds, which is equal to the draught per square t of chimney area. The height of a column of gas at the temrature within the chimney equal to this difference in weight is lled the head of the chimney, because it is this difference which oduces the draught or flow of air, just as the difference of level head produces the flow of water.

Rule *for finding the head of chimneys.*—Multiply the weight of ubic foot of air at the temperature of the outside air by the ight of the chimney and divide the product by the weight of e cubic foot of air at the temperature in the chimney. From quotient subtract the height of the chimney. The result will the head in feet.

Example.—If the temperature of the air is 32°, that in the imney 500°, and the height of the chimney 150 feet, the weight a cubic foot of the outside air will be

$$\frac{1}{12.5} = .08 \text{ pound,}$$

ile the weight of a cubic foot of air at the temperature of the imney will be

$$\frac{.08\,(32 + 460)}{500 + 460} = .041 \text{ pound.}$$

d hence the head

$$\frac{.08 \times 150}{.041} - 150 = 143 \text{ feet.}$$

If there were no obstruction to the passage of the gases, the locity of flow of air would be equal to the square root of the oduct of the head and the constant number 64.4. However, the ow is greatly impeded by the resistance opposed by the grate and e fuel, and by the friction of the sides of flues, tubes, and the lls of the chimney. Hence, the actual flow is very much less an this; how much less, depends upon the kind of grate and el, the thickness of fire, the condition of the flue walls, etc. It evident, therefore, that any rules which may be laid down for culating the *size of chimneys* will be largely the results of erience.

The following rules are based upon the assumption that effect of the friction is the same as though the area of the chin were contracted by an amount varying with the square root the height, and that it requires a consumption of five pound coal per hour to produce a horse-power.

Rule *for finding the effective area of a given stack.*—Subt from the actual area of the stack six-tenths of the square roo the actual area, or divide three-tenths of the horse-power by square root of the height in feet. The result will be the effec area in square feet.

Rule *for finding the area of a stack of given height.*—Divide hundredths of the number of pounds of coal consumed per h by the square root of the height of the stack in feet. The re will be the effective area in square feet.

Rule *for finding the area of a stack when the height is not give* Extract the fourth root of the cube of the number of pounds coal consumed per hour and multiply this by the constant n ber .07. The result will be the actual area of the stack in squ feet.

Rule *for finding the height of a chimney of given area.*—Di six-hundredths of the number of pounds of coal used per hou the effective area of the stack in square feet, and square the tient. The result will be the height in feet.

Rule *for finding the height of a chimney when the area is given.*—Divide the number of pounds of coal consumed per h by the area of the grate in square feet, and square the quoti Multiply this by the constant number 120, and divide the duct by the stack temperature. The result will be the heigh feet.

In calculating the dimensions of a stack or chimney by above rules the height is usually fixed in advance by local co tions, such as the quality of the coal, the height of surroun buildings, the topography of the country, etc. Stacks shoul *general* be higher than surrounding buildings and hills, pa *because* the gases issuing from them would be objectionable i

12 — 6.15 = 5.85 pounds, which is equal to the draught per square foot of chimney area. The height of a column of gas at the temperature within the chimney equal to this difference in weight is called the head of the chimney, because it is this difference which produces the draught or flow of air, just as the difference of level or head produces the flow of water.

Rule *for finding the head of chimneys.*—Multiply the weight of a cubic foot of air at the temperature of the outside air by the height of the chimney and divide the product by the weight of one cubic foot of air at the temperature in the chimney. From this quotient subtract the height of the chimney. The result will be the head in feet.

Example.—If the temperature of the air is 32°, that in the chimney 500°, and the height of the chimney 150 feet, the weight of a cubic foot of the outside air will be

$$\frac{1}{12.5} = .08 \text{ pound,}$$

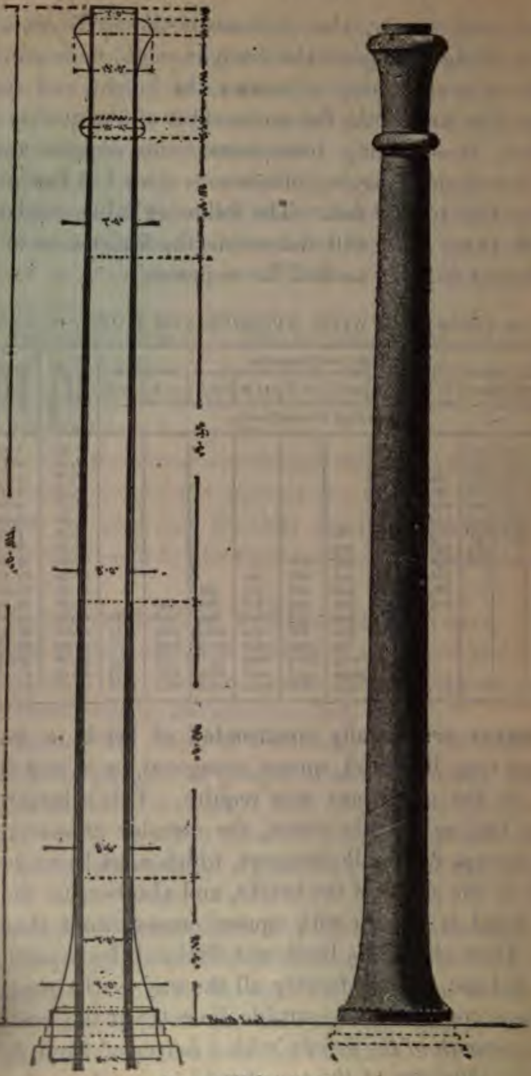
while the weight of a cubic foot of air at the temperature of the chimney will be

$$\frac{.08\ (32 + 460)}{500 + 460} = .041 \text{ pound.}$$

and hence the head

$$\frac{.08 \times 150}{.041} - 150 = 143 \text{ feet.}$$

If there were no obstruction to the passage of the gases, the velocity of flow of air would be equal to the square root of the product of the head and the constant number 64.4. However, the flow is greatly impeded by the resistance opposed by the grate and the fuel, and by the friction of the sides of flues, tubes, and the walls of the chimney. Hence, the actual flow is very much less than this; how much less, depends upon the kind of grate and fuel, the thickness of fire, the condition of the flue walls, etc. It is evident, therefore, that any rules which may be laid down for *calculating the size of chimneys* will be largely the results of *experience.*



Iron Chimney.

(8 or 9 inches) for a distance of 25 feet. If the height exceeds 160 feet, it should be a brick and a half, and it should increase in thickness one-half brick for each length of 25 feet to the bottom. An arched opening at the bottom should be provided to permit of access for cleaning and repairs, as well as a ladder either inside or outside to permit of access at the top.

Iron stacks are preferable in some cases to brick, because they are much cheaper, and, besides, their efficiency is somewhat higher. Furthermore, they are better able to withstand changes in temperature, which often cause brick chimneys to crack. Iron stacks are frequently built with firebrick linings. They should be firmly bolted down to a substantial brick foundation, and if not sufficiently heavy to withstand the pressure of the wind, they should be additionally stayed by guys to surrounding objects. They should be well painted, preferably with red lead, to prevent rusting, and should be provided with a ladder to permit of access to any part of the stack. The opening at the bottom is usually placed in the brick supporting-base, arched and provided with an iron door. The cut on page 308 shows an iron stack 170 feet high lined with firebrick.

QUESTIONS.

What is the function of a safety valve? How does it act?

What relation exists between the lift of a safety valve and the pressure? Explain the reason.

Name and describe the three principal kinds of safety valves, and explain the use of each.

Why is a lever safety valve with a weight at the end not fit for use on locomotive or marine boilers?

Describe the Lock-up Pop safety valve.

If the area of a lever safety valve is one square inch, the distance of the valve from the fulcrum 2 inches, the weight of the lever 2 pounds, and the distance of its centre of gravity from the fulcrum 5 inches, the weight of the valve and stem ½ pound, an the total length of the lever 15 inches, what weight must b placed on the end of the lever if it is to blow off at 100 poun per square inch?

If the dimensions of the safety valve are as specified in t previous example, and the weight is 12 pounds, at what pressu will the boiler blow off?

If the dimensions are again the same, and the weight is 1 pounds, at what distance should it be placed from the fulcrum, i the boiler is to blow off at 80 pounds per square inch?

At what distance from the fulcrum is the centre of gravity o a taper lever 12 inches long, the large end being 3 inches an the small end 1 inch wide?

Give the rules for areas of safety valves.

Describe the safety water column. What are its advantages?

Describe the Bourdon pressure gauge. What is the princip on which its action depends?

What is the object of the Econometer? What percentage of fu is wasted when the flue gases contain 10 per cent. of carbonic aci

What are the causes which produce an excessive supply of ai in boiler furnaces?

How high will an ordinary pump, in good condition, lift wate or other liquids?

What condition limits the action of all atmospheric pumps?

Give the rule for finding the size of pump-plunger and strok for an engine of any given power.

Give the rule for finding the quantity of water or other liqui that any pump will lift or discharge in any given time.

Give the most probable causes why pumps fail to work satisfactorily.

How is the theoretical power necessary to raise a given quantit of water computed?

What are the principal losses of power incident to pumpin water?

What are the three principal types of pumps used for feedin *ers?* Which type is most used? Why?

Name the three principal types of steam pumps. In what ential points do they differ?

Describe the duplex pump. What are its advantages over rect-acting pumps?

What precautions must be taken when pumping hot water?

What is an injector? Explain why it is possible by its use to rce water into the boiler against a pressure equal to or greater an that which operates it.

What are the parts of which an injector is composed? Explain e function of each.

What are the principal causes of failure in the working of jectors?

What is meant by the term "breaking" as applied to injectors?

What are the principal kinds of injectors? Explain their differences.

What is the difference between lifting and non-lifting injectors?

What precautions should be observed in the first installation of jectors?

What is an ejector? How does it differ from an injector?

Which is more economical, a pump or an injector? What are e advantages and disadvantages of each as appliances for feedg boilers?

Explain why the feed water should always be heated before it eaches the boiler.

What would be the difference in the amount of heat required evaporate 1000 pounds of water per hour from 60° and from 10° F.?

What methods are ordinarily employed for heating feed water?

Explain the difference between open and closed feed-water eaters. What are the advantages and disadvantages of the ro types?

What are the important points to be observed in selecting a osed feed-water heater?

What is an economizer? Why is it not employed in small *am plants?*

What is the object of a steam separator? What are the important points which should be observed in its design?

Explain why traps are essential in all steam plants. What should an efficient steam trap accomplish?

What is meant by a by-pass? Make a sketch showing how a feed-water heater would be piped with a by-pass for both steam and water.

In what respect does a cylinder, subjected to pressure from without, differ from one where the pressure acts from within?

What do the experiments of Fairbairn prove in regard to the strength of boiler flues?

Describe the different methods which are employed to strengthen boiler flues.

What pressure would cause a boiler flue 3 feet in diameter, 20 feet long, and ½ inch thick, to collapse if it were strengthened with a tee in the middle?

How are the furnaces of internally fired boilers usually made? Make a sketch showing how they are supported.

What determines the shape of grate bars and the width of spaces between them?

Why are grate bars often set at an angle instead of horizontal?

In what respect does a grate intended to burn bituminous coal differ from one intended for fine anthracite?

Explain the object of using shaking grates.

What are the advantages to be derived from the use of mechanical stokers?

What are the advantages to be derived from using coal dust as fuel?

What are the advantages to be derived from using oil as fuel?

Explain the causes which produce draught.

What is the best shape to give a chimney?

What are the causes which interfere with the satisfactory action of chimneys?

Explain the theory which underlies the proportioning of chim-

What is meant by the term *head* as applied to chimneys?

If the height of a chimney is 125 feet, the temperature of the ases in it 600°, and that of the surrounding atmosphere 60°, what ould be the head of the chimney?

Why is the draught of a chimney not equal to that which the ad is capable of producing?

Why is the effective area of a chimney less than the actual rea?

Calculate the effective area of a stack designed for 500 horse-ower, the height being 150 feet.

Explain how to go about designing a chimney for a given horse-ower, taking into account the surrounding conditions.

What shapes are given to chimneys of brick? What determines ese?

Give the rules for determining the outside dimensions of brick acks at different heights.

In what respects are iron stacks preferable to brick?

What are the principal points to be observed about iron stacks?

PART V.

THE STEAM ENGINE.

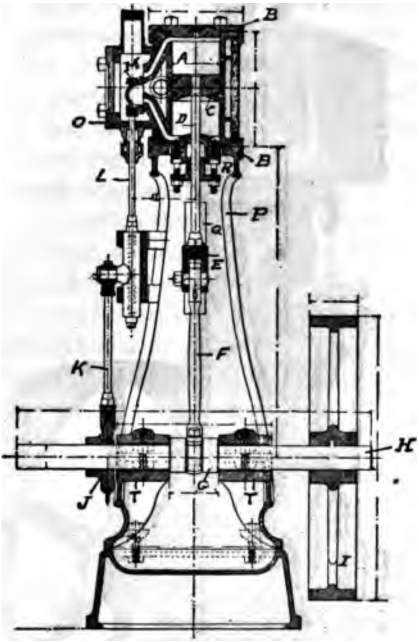
CHAPTER XVI.

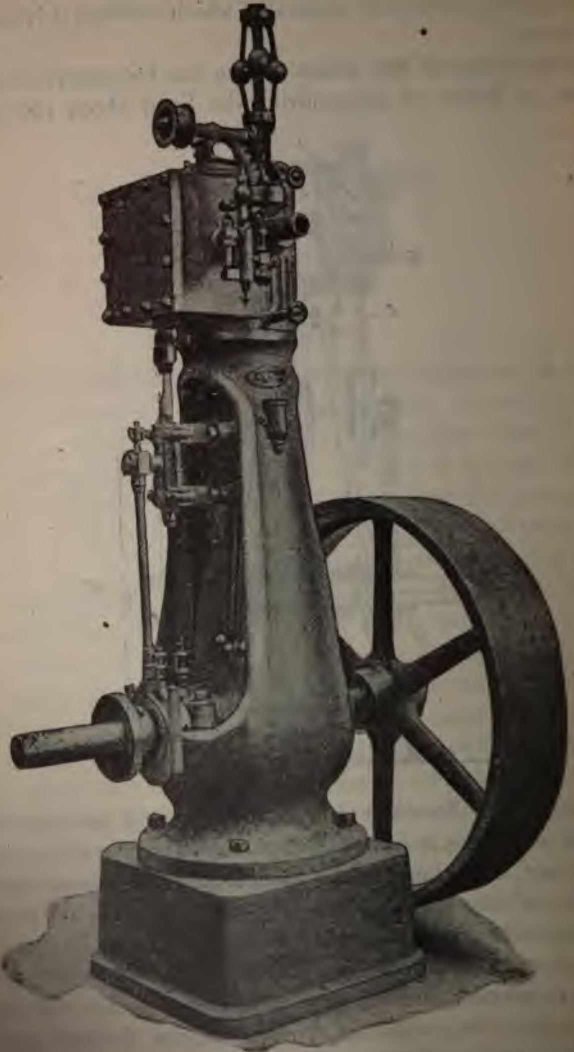
GENERAL.

The steam engine may be defined as an apparatus capable doing work by means of heat applied to water. It would be qui possible to perform all that it implied in this definition in single apparatus; for example, if we take a hollow cylind closed at the bottom and open at the top, and fill it to a heig of a few inches with water, upon which rests a flat plate fitti perfectly into the interior of the cylinder, and apply heat to t water, the following action will take place: After a few minut the water will begin to boil, giving off steam, which will accum late between the surface of the water and the disc or pisto which latter will be raised to make room for the steam. As w continue to apply heat more steam will be formed and the pisto will be raised higher. If we place a weight on the piston, th will be raised with it, and we have thus performed work in lifti the weight against the force of gravity. Hence, according to o definition, the simple apparatus described is a steam engine.

Such an arrangement would be of little value, however, actual practice, although with a few slight modifications it b comes a very useful and familiar device—a steam hammer, whi is the simplest form of a steam engine used at the present ti This, however, can be used for only one kind of work, namely, produce pressure, and it is not a steam engine in the sense which the term is generally used. The term steam engine, generally used, means an apparatus which delivers driving power from steam.

The invention of the steam engine has been accredited to the ancients, to Hero of Alexandria, who lived about 150 B. C., to the Marquis of Worcester in 1650 A. D., and various others; but there is no doubt whatever that the subject was not considered of any importance until the remarkable discoveries and inventions of James Watt from 1765 to 1790, who left to us the steam engine in almost the same form, in all of its essential features, as it exists at the present day. James Watt invented the separate condenser and air pump, the steam jacket, the double-acting engine, *the oscillating* cylinder engine, the ball governo *and throttle, and the steam* engine indicator, besides many of t





r essential parts of the steam engine. The later developments
e to Seguin, Ericsson, Stephenson, Fulton, and many others.
ow constructed, the steam engine proper has nothing to do
he generation of steam. This part of the operation is per-
l in the boiler, which has already been fully described,
; therefore remains for the steam engine to utilize the
as delivered from the boiler and transform the energy
is stored in it into useful work. The method by which this
omplished can best be illustrated by a description of a
form of steam engine. The sectional and perspective ele-
s of a vertical steam engine, on pp. 315, 316, show all of the
al parts of a modern steam engine. These comprise:

he steam cylinder, a hollow cylinder of cast iron, with ports
side for the admission and release of the steam.

he cylinder heads or covers, flat circular discs bolted to the
f the steam cylinder by means of flanges provided for that
e. In this particular engine the lower cylinder head is
one piece with the engine frame. This is frequently con-
t, though not necessary.

he piston, a circular disc, fitting tightly into the cylinder.
er to prevent leakage around the piston it is usually fitted
ast-iron *piston rings*, as shown in the sectional cut. These
de of slightly larger diameter than the piston and act as
s against the interior of the cylinder.

he piston-rod, a wrought-iron or steel rod, fastened rigidly at
d to the piston and at the other to

e cross-head, which is an intermediate part necessary for
nsformation of the reciprocating into rotary motion. As
r stated, the cross-head takes the piston rod at one end while
other it has a wrought-iron or steel pin, called the *wrist-pin*
-head pin.

e connecting rod, a wrought-iron or steel rod which has a
g at one end on the wrist-pin and at the other on the crank-
The *connecting rod is that* portion of the engine which
he transformation from reciprocating into rotary motion.

G, the crank, a lever or link which transmits the moti the end of the connecting rod to

H, the crank shaft, a revolving iron or steel axle, fro the power of the engine is taken.

I, the fly wheel, a heavy mass of metal, usually cast-iron ing with the crank shaft for the purpose of steadying the of the engine by virtue of its momentum.

J, the eccentric, an auxiliary crank for moving th mechanism. It consists of an eccentric disc keyed to th around which fits a brass ring, called the *eccentric stra* latter is bolted to a rod, which thus receives a recip motion, the amount of which depends on the *eccentricity* of the eccentric.

K, the eccentric rod, being the rod referred to above, attached to the eccentric strap. It is merely a link fo mitting the motion of the eccentric to

L, the valve rod, which is a rod attached to

M, the valve. This is one of the most important part engine, and is made in many different ways. In the illustrated above, it is a D-shaped casting sliding on a pl face, called the *valve seat.* The function of the valve i mit steam alternately to either end of the cylinder, a it has expanded and done its work on the piston to re and permit it to be exhausted. This is accomplished w aid of

N, the ports. These are simply passages through the wall, which are uncovered alternately to the steam which tained in the space around the valve, and to the exhaus communicates with the space beneath the valve. The ex led away through the pipe indicated by the circle in the passage.

O, the steam chest, a cast-iron casing which contains .. This is usually cast in one piece with the cylinde and is covered by a flat cast-iron plate, called ; which is bolted to it.

P, the frame or housing, by which the stationary parts of the engine are supported. This is made to suit the design of the ngine, it having no active part in the mechanism.

Q, the guides. These are, as their name indicates, pieces fast-ned to the frame, intended to guide the motion of the cross-head a straight line.

R, stuffing boxes, devices for preventing the leakage of steam here the piston and valve rods emerge respectively from the ylinder and steam chest. They consist of a small casting or *and* as shown, which fits into a recess, the latter being filled ith some fibrous material called *packing.* As the gland is rewed up the packing spreads and thus accomplishes its object.

S, the governor. This is not shown in the section, but will be en in place in the perspective view. The object of the governor to regulate the speed of the engine, keeping it constant under arying conditions of load and pressure. This may be accom-lished in various ways, as will be explained below (see "Govern-s" and "Descriptions of Various Types of Engines"). The ype of governor used in this engine is that known as the cen-rifugal throttling governor, consisting of two iron balls mounted n flat springs, which are attached at the top and bottom to a ertical spindle, the springs being free to move vertically at the ottom. The balls and springs rotate with the spindle, which eceives its motion from the engine shaft by means of a belt and ulleys. As the speed of the engine increases the balls have a ndency to move away from the spindle by virtue of their cen-rifugal force, and in so doing the bottom of the springs moves pward. This motion is transmitted to the throttle valve of the ngine in such a way as to close it partially when the speed creases, and *vice versa.* In this way the speed of the engine is gulated automatically.

T, the journals or bearings, which include all that portion of e engine frame, together with the caps, lining, etc., provided for olding *the shaft in position.* The bearings are usually provided ith *brass or soft metal linings,* to give a smooth bearing for th shaft. The caps are bolted down as shown and provided means of taking up the wear.

These are the essential parts of a steam engine, but th various devices such as keys, gibs, lubricators, throttle tagging, etc., used in connection with it. These are her ted, because they are merely details in the construction engine.

Power of Steam Engines.

The power which a steam engine can furnish is gener pressed in "horse-power," the "nominal horse-power" admitted to be a force capable of raising a weight of pounds one foot high* in one minute, or 150 pounds 220 fe in the same length of time. If an engine is rated at 25 power, it is recognized as being capable of raising 33,000 one foot high twenty-five times in each minute. The quest naturally arise, How are these 33,000 pounds to be raised answer to which would be, by *belts, pulleys, cog-gearing, paddle wheels, screw-propellers,* or *whatever mechanical arra* is most practicable and convenient.

There are several terms employed to express the powe gines, such as the "nominal," "indicated," "actual or net namo-metrical," and "commercial" horse-power. The *i* *horse-power* is obtained by multiplying together the mean e pressure in the cylinder as shown by the diagram, the are piston in square inches, and the speed in feet per minu dividing the product by 33,000. The *actual* or *net hors* the total available power, and is equal to the indicated less the amount necessary to overcome the frictio *metrical* or *brake horse-power* is the horse-power measured at the driving pulley by means of ke, and is equal to the net horse-power. W wer is used in reference to steam en e indicated horse-power. The method of ascertaining al horse-power will be explained under "The Steam ndicator."

---

* Foot-pounds.

orse-power of a steam engine is determined by four iz.:

mean effective or average pressure,*
length of stroke,
diameter of cylinder,
number of revolutions of crank.

1 the horse-power of any engine:

—Multiply the mean effective pressure* on the piston in er square inch by the area of the piston in square inches; this product by twice the product of the length of the feet and the number of revolutions per minute; divide product by 33,000, and the quotient will be the horse- the engine.

le.—What is the horse-power of an engine under the conditions:

Mean effective pressure, 40 lbs. per sq. in.
Diameter of cylinder, 18″.
Stroke, 24″.
Speed, 200 revolutions per minute.

ea of the piston is:

$$.7854 \times 18 \times 18 = 254 \text{ square inches,}$$

e stroke in feet, $\frac{24}{12} = 2$ feet,

e the horse-power by the above rule is:

$$\frac{40 \times 254 \times 2 \times 2 \times 200}{33,000} = 246 \text{ horse-power.}$$

d the diameter of a steam cylinder to develop a given ver under a given mean effective pressure and at a given eed:

—Multiply the horse-power by 33,000 and divide this by the product of the piston speed in feet per minute, the mean effective or average pressure, and the decimal .7854. square root of the quotient will be the required diameter o cylinder.

---

*See mean effective pressure, page 327 and tables.

Example.—What diameter of cylinder would be required engine which is to deliver 90 horse-power under a mean eff pressure of 40 pounds per square inch and a piston speed o feet per minute?

$$\sqrt{\frac{90\times 33000}{40\times 560\times .7854}}=\sqrt{\frac{2970000}{17593}}=\sqrt{169}=13 \text{ inches.}$$

If the length of stroke is 12 inches, how many revolutio minute should the engine make? The piston speed being feet per minute and the length of stroke 12 inches or 1 foo number of strokes per minute will be 560 ÷ 1 = 560, and the number of revolutions, which is one-half the number of st will be 280.

These and other rules concerning the horse-power of er can all be expressed by a few simple formulæ as follows:

Let A = area of piston in square inches.
D = diameter " inches.
L = length of stroke in feet.
S = piston speed in feet per minute.
N = number of strokes per minute.
R = " revolutions per minute.
P = mean effective or average pressure in pounds per s inch.
HP = horse-power.

$$HP=\frac{PLAN}{33000}=\frac{PSA}{33000}=\frac{PLAR}{16500}=\frac{PLD^2R}{21010}$$

$$D=\sqrt{\frac{A}{.7854}}=\sqrt{\frac{33000HP}{.7854PLN}}=145\sqrt{\frac{HP}{PLR}}$$

$$S=NL=2RL$$

For condensing engines the same rules and formulæ a
that case the mean effective pressure must be increas
t corresponding to the degree of vacuum. For exa
ne runs condensing under 80 pounds initial p

ut-off, and 26 inches of vacuum, the mean effective pressure is 97+13=54.97 pounds, which value used in the above formulæ uld give the horse-power.

Example.—What diameter of cylinder would be required for a horse-power condensing engine, running at 200 revolutions minute, with an initial pressure of 80 pounds per square inch d ¼ cut-off, the stroke being 24 inches and the vacuum 24 ches?

The piston speed is

$$\frac{2 \times 200 \times 24}{12} = 800 \text{ feet per minute.}$$

e mean effective pressure is

$$41.97 + \frac{24}{2} = 53.97 \text{ pounds.}$$

nce the diameter of cylinder required would be

$$\sqrt{\frac{200 \times 33{,}000}{800 \times 53.97 \times .7854}} = \sqrt{195} = 14 \text{ inches.}$$

TABLE

INDICATED HORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT SPEEDS AND PRESSURES.*

The following table is calculated for ¼ cut-off. For any other -off look up the corresponding mean effective pressure; divide by the mean effective pressure for ¼ cut-off, and multiply the otient by the value of the horse-power in the table. Thus a ×12 engine at 300 revolutions, 80 pounds pressure, and ¼ cut-off uld develop 57.12 horse-power, while at ⅜ cut-off and same ed, its horse-power would be:

$$57.12 \times \frac{55.85}{41.97} = 76.01 \text{ horse-power.}$$

---

he values of the mean effective pressure used in this table are not , but they are sufficiently so for all practical purposes. See table on [illegible]

INDICATED HORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT SPEEDS AND PRESSURES.

Cutting off Steam [illegible] Stroke, 40, 45 and 50 Pounds Mean Effective.

Size of Engine.	Revolutions per minute.	Initial Steam Pressure.		
		80	90	100
6 x 8	350	16.00	18.00	20.00
	400	18.15	20.60	22.90
	450	20.50	23.20	25.75
6 x 10	300	17.13	19.27	21.41
	330	18.84	21.20	23.55
	350	19.98	22.48	24.98
7 x 8	350	21.90	24.50	27.20
	400	24.90	28.05	31.05
	450	28.00	31.50	35.00
7 x 10	300	23.32	26.23	29.15
	330	25.64	28.86	32.07
	350	27.20	30.61	34.01
8 x 8	350	28.40	32.00	35.50
	400	32.50	36.56	40.60
	450	36.50	41.10	45.70
8 x 10	300	30.46	34.27	38.08
	330	33.50	37.69	41.88
	350	35.53	39.98	44.42
8½ x 10	300	34.30	38.75	43.00
	330	37.75	41.50	47.20
	350	40.10	45.00	50.10
[illegible]	300	42.95	48.32	53.69
	330	47.25	53.16	59.06
	350	50.13	56.38	62.64
[illegible]	250	38.52	43.34	48.19
	280	43.15	48.20	53.97
	300	46.24	51.44	57.83
[illegible]	300	47.70	53.50	59.60
	[illegible]	52.40	59.00	65.50
	[illegible]	55.50	62.60	69.50
[illegible]	[illegible]	47.60	53.55	59.50
	[illegible]	53.31	59.98	66.64
	[illegible]	57.12	64.26	71.40
[illegible]	[illegible]	57.59	64.79	71.99
	[illegible]	64.50	72.56	80.63
	[illegible]	[illegible]	77.75	86.39

DICATED HORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT SPEEDS AND PRESSURES.

Cutting off Steam ¼ Stroke, 40, 45, and 50 Pounds Mean Effective.

Size of Engine.	Revolutions per Minute.	Initial Steam Pressure.		
		80	90	100
12 x 12	250	68.52	77.08	85.65
	280	76.75	86.34	95.94
	300	82.24	92.52	102.80
13 x 12	250	80.44	90.50	100.55
	280	90.09	101.36	112.62
	300	96.53	108.60	120.66
14 x 12	250	93.29	104.95	116.61
	280	104.48	117.54	130.60
	300	111.94	125.94	139.93
15 x 14	245	122.44	137.75	153.06
	265	132.44	149.00	165.55
	275	137.50	155.00	171.50
16 x 14	245	139.50	156.30	174.20
	265	151.00	169.50	187.50
	275	156.00	176.50	195.00
15 x 16	200	114.24	128.52	142.80
	230	131.16	147.55	163.95
	240	137.08	154.21	171.35
16 x 16	200	130.00	146.25	165.50
	230	148.24	166.77	185.30
	240	155.96	175.45	194.95
17 x 16	200	136.75	165.50	183.25
	230	167.50	188.00	209.00
	240	176.00	198.00	220.00
18 x 16	200	164.46	185.01	205.57
	230	189.13	212.77	236.41
	240	197.35	222.02	246.69
19 x 18	200	206.18	231.95	257.72
	210	216.51	243.57	270.64
	220	226.82	255.17	283.53
20 x 18	200	228.43	256.99	285.54
	210	239.90	269.89	299.88
	220	251.30	282.74	314.16
22 x 18	200	267.00	311.00	345.50
	210	290.00	327.00	262.50
	220	304.50	342.50	380.00

TABLE

ENGTH OF STROKE AND NUMBER OF REVOLUTIONS FOR DIFFERENT PISTON SPEEDS IN FEET PER MINUTE.

STROKE.	SPEED OF PISTON IN FEET PER MINUTE.														
	Ft. 360	370	380	390	400	410	420	430	440	450	460	470	480	490	500
	Rev.														
1 ft. 6 in.	120	123	126	130	133	136	140	143	146	150	153	156	159	163	166
1 " 8 "	108	111	114	117	120	123	126	129	132	135	138	141	144	147	150
1 " 10 "	98	101	103	104	109	112	114	117	120	122	125	128	131	133	136
2 " 0 "	90	92	95	97	100	102	105	107	110	112	114	117	120	122	125
2 " 3 "	80	82	84	86	89	91	93	95	97	100	102	104	106	108	111
2 " 6 "	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
2 " 9 "	65	67	70	71	72	74	76	78	80	81	83	85	87	89	91
3 " 0 "	60	61	63	65	66	68	70	71	73	75	76	78	80	81	83
3 " 3 "	55	56	58	60	61	63	64	66	67	69	70	72	74	75	76
3 " 6 "	51	52	54	55	57	58	60	61	62	64	65	67	68	70	71
3 " 9 "	48	49	50	52	53	54	56	57	58	60	61	62	64	65	66
4 " 0 "	44	46	47	48	50	51	52	53	55	56	57	58	60	61	62
4 " 3 "	42	43	44	45	47	48	49	50	51	53	54	55	56	57	58
4 " 6 "	40	41	42	43	44	45	46	47	48	50	51	52	53	54	55

ın Effective Pressure.—After cut-off the steam, which pre-
y had a pressure equal to that of the boiler, expands, forcing
ston to the other end of the cylinder. In proportion to its
se in volume the steam loses in pressure and the product of
re at any time by volume at that time is very nearly a con-
uantity (whence it is said to follow the *hyperbolic law*, from
t that the product of the ordinates of a hyperbola are con-

Knowing the initial pressure and the relative volumes
beginning and end of expansion, we can compute the press-
any point of stroke or the average pressure exerted over
ıole stroke.

e for finding the mean or average pressure in the cylinder
engine, assuming expansion according to the hyperbolic law.
ide the length of the stroke in inches (including the clear-
by the distance that the steam follows the piston before
cut off; the quotient will be the expansion the steam under-
Then find in the expansion column, in the following table,
mber corresponding to it; take the multiplier opposite, and
ly the full pressure of the steam per square inch, as it enters
linder, by it. The product will be the average pressure.

mple.—Suppose the initial pressure be 70 lbs. per sq. inch
ıt-off at half-stroke, the stroke being 3 ft.

Then 3 ft. = 36 in. + 0·5 for clearance = 36·5.
Stroke ½ = 18 in. + 0·5 " = 18·5.

36·5 ÷ 18·5 = 1·97, the relative expansion between 1·9
. By referring to the table, the multiplier for 1·9 will be
to be 0·864, and the difference between that and the multi-
for 2 is 0·017. Hence, by multiplying 0·017 by ·7, and sub-
ıg the product ·012, the remainder, 0·85281, is the multi-
for 1·97. Therefore, 0·85281 × 70 = 59·697 lbs. per sq.
the mean forward pressure on the piston. Ordinarily the
works against a back pressure which lessens the value of
sultant force acting on the piston at any moment. Hence,
the *mean effective pressure* (written M. E. P.), deduct the
e back pressure from the average forward pressure.

TABLE

OF MULTIPLIERS BY WHICH TO FIND THE MEAN PRESSURE OF STEA VARIOUS POINTS OF CUT-OFF.

Expansion.	Multiplier.	Expansion.	Multiplier.	Expansion.	Multiplie
1·0	1·000	3·4	·654	5·8	·479
1·1	·995	3·5	·644	5·9	·474
1·2	·985	3·6	·634	6·	·470
1·3	·971	3·7	·624	6·1	·466
1·4	·955	3·8	·615	6·2	·462
1·5	·937	3·9	·605	6·3	·458
1·6	·919	4·	·597	6·4	·454
1·7	·900	4·1	·588	6·5	·450
1·8	·882	4·2	·580	6·6	·446
1·9	·864	4·3	·572	6·7	·442
2·	·847	4·4	·564	6·8	·438
2·1	·830	4·5	·556	6·9	·434
2·2	·813	4·6	·549	7·	·430
2·3	·797	4·7	·542	7·1	·427
2·4	·781	4·8	·535	7·2	·423
2·5	·766	4·9	·528	7·3	·420
2·6	·752	5·	·522	7·4	·417
2·7	·738	5·1	·516	7·5	·414
2·8	·725	5·2	·510	7·6	·411
2·9	·712	5·3	·504	7·7	·408
3·	·700	5·4	·499	7·8	·405
3·1	·688	5·5	·494	7·9	·402
3·2	·676	5·6	·489	8·	·399
3·3	·665	5·7	·484		

TABLE

OF CONSTANT NUMBERS, BY WHICH TO ASCERTAIN THE AVERAGE P URE OF THE STEAM AGAINST THE PISTON FOR DIFFERENT PRESSU AND POINTS OF CUT-OFF, FROM $\frac{1}{4}$ TO $\frac{7}{8}$ OF THE STROKE.

Point of Cut-off.	Constant Number.	Point of Cut-off.	Constant Numb
$\frac{1}{4}$	·5965	$\frac{5}{8}$	·9188
$\frac{1}{3}$	·6995	$\frac{2}{3}$	·9370
$\frac{3}{8}$	·7428	$\frac{3}{4}$	·9657
$\frac{1}{2}$	·8465	$\frac{7}{8}$	·9919

Multiply the pressure in pounds, as shown by the gauge, by constant number opposite the point of cut-off in the left he product is the average pressure.

TABLE

OF INDICATED HORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT PISTON SPEEDS.

The following table is calculated for one pound mean effective pressure. Hence the horse-power in the table is to be multiplied by the mean effective pressure as obtained from the indicator diagram or from the table. (See page 328.)

INDICATED HORSE-POWER FOR EACH POUND AVERAGE PRESSURE PER SQUARE INCH, WITH DIFFERENT DIAMETERS AND SPEEDS OF PISTON.

Diameter of Cylinder.	SPEED OF PISTON IN FEET PER MINUTE.							
	240	300	350	400	450	500	550	600
inches.								
4	·091	·114	·133	·152	·171	·19	·209	·228
4½	·115	·144	·168	·192	·216	·24	·264	·288
5	·144	·18	·21	·24	·27	·30	·33	·36
5½	·173	·216	·252	·288	·324	·36	·396	·432
6	·205	·256	·299	·342	·385	·428	·471	·513
6½	·245	·307	·391	·409	·461	·512	·563	·614
7	·279	·348	·408	·466	·524	·583	·641	·699
7½	·321	·401	·468	·534	·602	·669	·735	·802
8	·365	·456	·532	·608	·685	·761	·837	·912
8½	·413	·516	·602	·688	·774	·86	·946	1·032
9	·462	·577	·674	·770	·866	·963	1·059	1·154
9½	·515	·644	·751	·859	·966	1·074	1·181	1·288
10	·571	·714	·833	·952	1·071	1·390	1·309	1·428
10½	·63	·787	·919	1·050	1·181	1·313	1·444	1·575
11	·691	·864	1·008	1·152	1·296	1·44	1·584	1·728
11½	·754	·943	1·1	1·257	1·414	1·572	1·729	1·886
12	·820	1·025	1·195	1·366	1·540	1·708	1·880	2·050
13	·964	1·206	1·407	1·608	1·809	2·01	2·211	2·412
14	1·119	1·398	1·631	1·864	2·097	2·331	2·564	2·797
15	1·285	1·606	1·873	2·131	2·409	2·677	2·945	3·212
16	1·461	1·827	2·131	2·436	2·741	3·045	3·349	3·654
17	1·643	2·054	2·396	2·739	3·081	3·424	3·766	4·108
18	1·849	2·312	2·697	3·083	3·468	3·854	4·239	4·624
19	2·061	2·577	3·006	3·436	3·865	4·295	4·724	5·154
20	2·292	2·855	3·331	3·807	4·265	4·759	5·234	5·731
21	2·518	*3·148*	*3·672*	4·197	4·722	5·247	5·771	6·296
22	*2·764*	*3·455*	*4·031*	4·607	5·183	5·759	6·334	6·91

TABLE—(*Continued.*)

INDICATED HORSE-POWER FOR EACH POUND AVERAGE PRI PER SQUARE INCH, WITH DIFFERENT DIAMETERS AND SPEEDS OF PISTON.

Diameter of Cylinder.	SPEED OF PISTON IN FEET PER MINUTE.						
	240	300	350	400	450	500	550
Inches.							
23	3·021	3·776	4·405	5·035	5·664	6·294	6·923
24	3·289	4·111	4·797	5·482	6·167	6·853	7·538
25	3·569	4·461	5·105	5·948	6·692	7·436	8·179
26	3·861	4·826	5·630	6·435	7·239	8·044	8·848
27	4·159	5·199	6·066	6·932	7·799	8·666	9·532
28	4·477	5·596	6·529	7·462	8·395	9·328	10·261
29	4·805	6·006	7·007	8·008	9·009	10·01	11·011
30	5·141	6·426	7·497	8·568	9·639	10·71	11·781
31	5·486	6·865	8·001	9·144	10·287	11·43	12·573
32	5·846	7·308	8·526	9·744	10·962	12·18	13·398
33	6·216	7·770	9·065	10·360	11·655	12·959	14·245
34	6·59	8·238	9·611	10·984	12·357	13·73	15·103
35	6·993	8·742	10·199	11·656	13·113	14·57	16·027
36	7·401	9·252	10·794	12·336	13·878	15·42	16·962
37	7·819	9·774	11·403	13·032	14·861	16·29	17·919
38	8·246	10·308	12·026	13·744	15·462	17·18	18·898
39	8·648	10·86	12·67	14·48	16·29	18·1	19·91
40	9·139	11·424	13·328	15·232	17·136	19·04	20·944
41	9·604	12·006	14·007	16·008	18·009	20·00	22·011
42	10·065	12·594	14·693	16·792	18·901	20·99	23·089
43	10·56	13·20	15·4	17·6	19·8	22·0	24·2
44	11·046	13·818	16·121	18·424	20·727	23·03	25·333
45	11·563	14·454	16·863	19·272	21·681	24·09	26·399
46	12·086	15·128	17·626	20·144	22·662	25·18	27·698
47	12·614	15·768	18·396	21·024	23·652	26·28	28·908
48	12·846	16·446	19·187	21·928	24·669	27·41	30·151
49	12·913	17·142	19·999	22·856	25·713	28·57	31·427
50	14·28	17·85	20·825	28·8	26·775	29·75	32·725
51	14·832	18·54	21·665	24·76	27·855	30·95	34·045
52	15·437	19·296	22·512	25·728	28·944	32·16	35·376
53	16·041	20·052	23·394	26·736	30·078	33·42	36·762
54	16·656	20·82	24·29	27·76	31·23	34·7	38·17
55	17·275	21·594	25·193	28·792	32·391	35·99	39·589
56	17·909	22·386	26·117	29·848	33·579	37·31	41·041
57	18·557	23·196	27·062	30·928	34·794	38·66	42·526
58	19·214	24·018	28·021	32·024	36·027	40·03	44·033
59	19·902	24·852	28·994	33·136	37·278	41·42	45·562
60	20·558	25·698	29·981	34·264	38·547	42·83	47·11

Classification of Engines.

m engines may be classified in various ways:

Vith regard to the piston speed, they may be divided into

High-speed engines,
Slow-speed engines.

rom the method of disposing of the steam after passing h the engine cylinder, into

Condensing engines,
Non-condensing engines.

ccording to the number of cylinders in which the steam ls successively, into

Simple engines,
Compound engines,
Triple expansion engines,
Quadruple expansion engines, etc.

ccording to the method of regulating the speed, into

Throttling engines,
*Variable cut-off engines.**

rom the standpoint of the kind of work which the engine perform, into

Stationary engines,
Marine engines,
Locomotive engines.

ccording to the action of the steam pressure being on one the piston only, or on both sides, into

Single-acting engines,
Double-acting engines.

rom the nature of the motion of the piston, into

Reciprocating engines,
Rotary engines.

---

e speed is kept constant by varying the cut-off, this class of engines l automatic cut-off engines. There are more automatic cut-off n use than any other type.

All steam engines must belong to at least one of t classes, and many belong to several. For example, a may be a compound, condensing, high speed, automati double-acting, stationary engine, and, in fact, there a such in use. The classification might have been carri erably further by recognizing differences in the detail struction as constituting different classes, but this woul too far and the classification adopted will be quite su bring out the essential points in which steam engines d construction and method of operation.

High-speed and Slow-speed Engines.

The term high-speed engines, though sometimes include only engines which run at a high speed of rotati in reality engines with high piston speeds. The ideas builders in regard to what is a high piston speed have cha materially during the last quarter of a century, so muc engines which in 1870 were considered as high speed w be classed as extremely slow-speed engines. At the Inte Exposition in Vienna, in 1873, the average piston spe engines there exhibited was about 350 feet per minute maximum about 420 feet per minute, while the sam exhibited in 1888 at the Vienna Industrial Exhibitio whose average piston speed was about 480 feet per min maximum of nearly 700 feet per minute. At the Inte Exposition in Paris, in 1889, piston speeds of 780 feet attained, and at the Electrical Exposition in Frankfurt the maximum was 875 feet per minute. In large engin 900 feet per minute is not considered extraordinary, an even in small electric lighting engines of the type know speed engines, meaning high rotary speed, that between 800 feet per minute is the ordinary piston velocity.

The advantages of high-speed over slow-speed eng *be briefly* stated as follows:

First.—For a given steam pressure and cut-off the ngine varies directly as its speed. There are four factors which etermine the power of an engine, viz.:

(*a*) The mean effective pressure on the piston.
(*b*) The length of the stroke.
(*c*) The area of the piston.
(*d*) The speed.

In other words, an engine of a given diameter and length of roke, acting under a given mean effective pressure, will develop ower in proportion to its speed, and if the speed is doubled its ower will also be doubled, and so to obtain a given power under given mean effective pressure we need make an engine only alf as large if we double its speed. Hence we have as the first rgument for high speeds, economy both in first cost and in space.

Secondly.—In most cases where power is supplied by a steam ngine it must be transmitted to other shafting, which usually uns at a much higher speed. Now whether this transmission is y belt, by toothed wheels, or by friction gearing, it can be perormed more efficiently if the ratio of the speeds is not too great. n many cases, where the power is transmitted by belting the atio of speeds is too great to admit of transmission in a single tep, since the arc of contact on the driven pulley would be too mall to prevent serious slippage of the belt. In such cases it is ommon to use an intermediate shaft, which performs no other luty than to make the reduction more gradual, and thus to insure satisfactory running of the belt. By increasing the speed of he engine this is done away with in many cases. In fact, in the ase of dynamo machines, which, until recently, were nearly lways driven through an intermediate or counter shaft, it is now ommon practice to couple the shafts of engine and dynamo irect, without any belting whatever. In spite of all that may be aid against this practice, it cannot be denied that it often saves a ery considerable amount of valuable space.

Thirdly.—It is claimed for high-speed steam engines that the conomy in *the use of steam* far exceeds that of the older forms f *slow-speed engines.* There is no doubt a great deal of justic in this claim, because one of the main losses in the engine, the cooling of the cylinder walls and passages during exh and re-evaporation is greatly reduced. The disadvantage admitting steam by the same channels through which it exha is clearly demonstrated in the increased economy of the Co type of engine, where this is not the case.

As far as re-evaporation is concerned, it is of course obv that the cylinder walls are chilled very considerably during process, and the more steam is passed through the engine given space of time the less will be the re-evaporation. H the increased economy of the high-speed engine.

Finally.—It is a fact that the uniformity and smoothnes running are much better in high-speed engines than in s speed engines. This is due partly to the fact that the influ of the fly-wheel is greatly enhanced and partly to the stead influence of the reciprocating parts. It is a well-known fact the steadying action of a fly-wheel is proportional to the sq of its speed, which means that if one engine runs twice as fas another of the same design and same weight of fly-wheel, it run four times as steady.

The influence of the reciprocating parts on the running o engine, in order to be thoroughly understood, requires a l more consideration. In a steam engine revolving with a unif velocity all the parts which move to and fro—the reciproca parts—come to rest at the beginning and end of each str The reciprocating parts consist of the

piston,
piston rod,
cross head, and
connecting rod.

When the stroke is reversed they are gradually set in mot
ly at first, and faster until the middle of the stroke, w
re moving with the same velocity as the crank-pin.

at their motion is retarded until the end of the stroke, when ey again come to rest and the same action is repeated. Now, order to set a body in motion it is necessary to apply force to , and the amount of force depends on its mass or weight and the elocity of motion. A body once set in motion no longer requires ny force to keep it moving uniformly; but so long as its motion increasing, so long must force be applied to it, the amount that ust be applied being in proportion to the rate of increase of elocity. The reverse of this is also true. If a body is moving ith a certain velocity and this is decreased, the body exerts a rce on whatever is tending to stop it, and here too the amount f force which it exerts is in proportion to the rate of decrease of s velocity. This is a familiar fact in mechanics, and is often llustrated in text-books by the case of a railroad train, which equires a certain force to get it up to speed. After it has ttained this it requires no more energy to keep it in motion, but ll that is supplied to it in the shape of steam is used up in overoming the friction. Just so it is with the reciprocating parts. At he beginning of the stroke they require a comparatively great force o start them from rest, which becomes less and less until the middle, when it requires none at all, for they are now up to the speed—hat is, moving with the same velocity as the crank-pin. After this heir motion is gradually retarded until the end of the stroke, hen they come to rest completely. Now in every steam engine he pressure is a maximum at the beginning of the stroke, decreasing as the stroke advances until the end, when it is a minimum; ence it is evident that the action of the reciprocating parts, hich is to absorb or store a portion of the pressure during the irst half of the stroke and restore it during the second half, has he effect of tending to keep the pressure on the crank uniform during the entire stroke, or, in other words, to steady the running f the engine.

High-speed engines must be high-pressure engines—that is, he *steam pressure at the* beginning of the stroke must be suf*cient always to set the* reciprocating parts in motion, and th pressure must never be reduced by means of the throttle va otherwise the engine will be subjected to strains which will im its life. For the same reason the governor should change cut-off and not the steam pressure. The reciprocating p should be made as light as is consistent with strength, hence they should be made of steel. The steam ports sh be carefully considered in the design; the higher the speed larger the steam passages, otherwise the pressure will be redu before entering the cylinder. The steam should be cut off ea and there should be a moderate amount of compression—tha the exhaust should be closed before the end of the stroke, in o to provide a cushion for bringing the reciprocating parts to In other respects there is no difference between high-speed slow-speed engines. Their design is essentially alike, and co quently it will not be necessary here to describe engines of t two classes, as the only apparent difference would be that regulation of the speed or governing of the one would be by me of a device for changing the cut-off, and in the other by me of a device for changing the initial steam pressure. In ot respects the difference between the two types is merely a di ence of degree and not of kind. (For descriptions of diffe kinds of governors, see page 416.)

Non-condensing and Condensing Engines.

In the non-condensing engine the steam, after acting on piston, escapes into the open air; therefore the pressure of outgoing steam must exceed atmospheric pressure, or 14.7 pou to the square inch. Thus, if steam at 45 pounds average pr ure above vacuum be admitted to the piston of a high-pres engine, it will exert a force equal to its pressure; but 14.7 pou per square inch of that pressure will not be converted into w as it will be lost in overcoming the pressure of the atmosph which may be illustrated by the following example:

Diameter of cylinder, 12 in.; area, 113·09 in.
Average steam pressure per square inch, 45 lbs.
Total steam pressure, 5089·05 lbs.

As before, area, 113·09 sq. in.
Atmospheric pressure, 14·7 lbs.
Total atmospheric pressure, 1662·423 lbs.

5089·050
Loss due to atmospheric pressure, 1662·423
Effective steam pressure on piston, 3426·627 lbs.

he foregoing example shows the resistance to be overcome at stroke of the piston before the steam acting against it can uce any useful effect. Thus it will be seen that the piston high-pressure steam-engine is exposed to the action of two ures, namely, the pressure of the steam from the boiler on ide, and that due to the atmosphere and the steam remaining e cylinder after exhaust takes place on the other. The ure utilized or converted into work will be the difference een the two.

the condensing engine the steam, after acting against the n, escapes into a condenser, where it is condensed into water a vacuum is formed, thus rendering not only a considerable on of the steam pressure in the boiler, but also the 14.7 ds per square inch required in the non-condensing engine to come the pressure of the air available as an effective force nst the piston, which may be explained as follows:

Diameter of cylinder, 12 in.; area, 113.09 sq. in.
Average steam pressure per sq. in., 45 pounds.
Total steam pressure, 5089.05 lbs.

As before, area, 113.09 sq. in.
Pressure in condenser, at best, 2 lbs.
Total back pressure, 226.18 lbs.

5089.05
226.18
Effective pressure on piston, 4862.87

The back pressure in the condenser, which represents the d ference between the indications of the vacuum-gauge and a p fect vacuum, must be deducted; but as a perfect vacuum is n attainable, the back pressure varies from 2 to 5 pounds, acco ing to the condition of the engine and the quantity of unco densed steam remaining in the condenser.

Advantages of the Condensing over the Non-condensing E gine.—When the resistance of the atmosphere is removed from t piston the steam may be cut off earlier and further expanded the cylinder. This reduces the draught on the boiler and adm of a slower combustion of the fuel. In this way economy is p moted by condensation of the exhaust steam and by the vacu formed in the cylinder. A vacuum equal to 14 pounds mea roughly 35 per cent. saving in fuel, or the same increase in powe but this saving undergoes a great reduction in consequence of t cylinder being open alternately to the lower temperature in t condenser, which varies with the degree of expansion employe being least when the steam follows full stroke, which is ve seldom the case. The practical gain, therefore, in the condensi engine is from 20 to 30 per cent., varying with the conditio above named, as shown in the working of condensing engin both stationary and marine. The economy of the condensing gine might be increased, if advantage could be taken (as in t case of the injector and steam-jet) of the velocity with which t exhaust steam escapes from the cylinder to the condenser. entering the condenser, the power due to its energy is entirely stroyed by the cold water injection, or by being brought in cont with refrigerating surfaces.

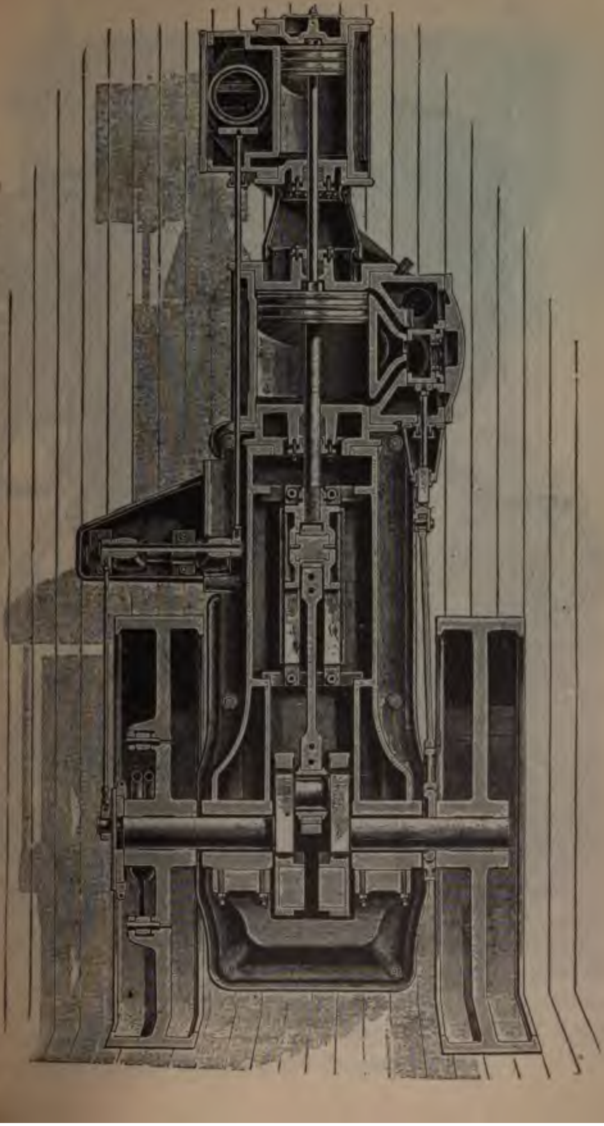
The difference in effect between the condensing and non-c densing engine, with equal pressure of steam and expansion, shows that the condensing engine has the advantage of the eff produced by the vacuum, or the amount of atmospheric press removed. Their difference in operation is, that in the condensi engine, the steam, after having performed its duty in the cylind condensed by the admission of a spray of cold water, or bi t in contact with cooling surfaces, thus producing a vacuum *us* pressure, which varies, according to the perfection of the iery, from 10 to 13 lbs. per square in.; while in the non-con- engine, the steam, after having performed its duty, is ged into the atmosphere. Thus, the advantages of the n are lost; some of the waste heat, however, is utilized by the exhaust steam through a heater, for the purpose of the feed-water. For this reason small simple engines are run as condensing engines. The slight gain in economy ie use of a condenser is usually more than balanced by the ed first cost and the disadvantage of feeding cold or impure o the boilers. Condensers are frequently added, however, purpose of increasing the power of existing engines. There essential difference in the design of condensing and non-sing engines.

Simple and Multiple Expansion Engines.

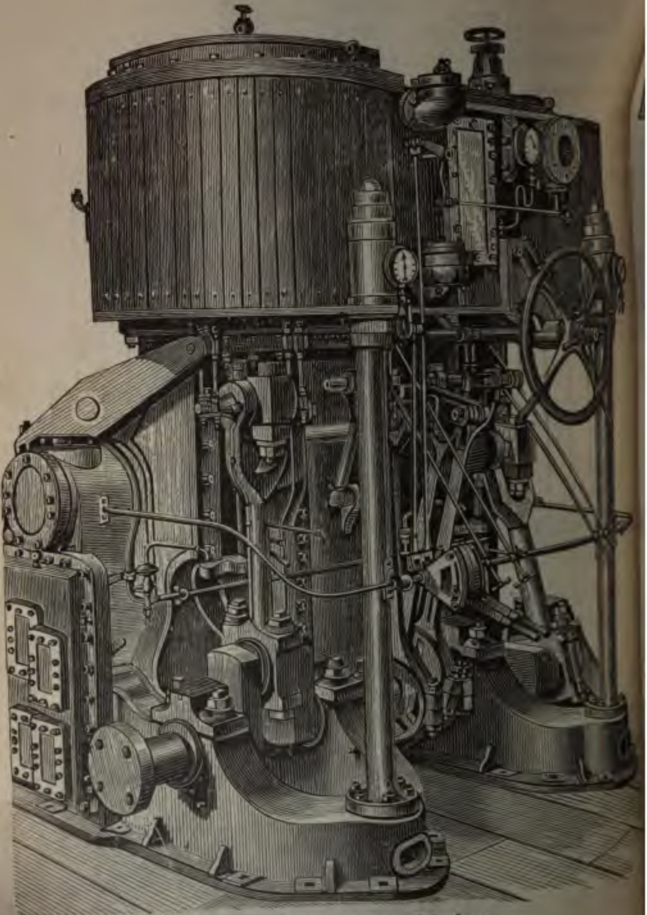
ple engines are those in which the steam is used for per- work only once. It makes no difference how many cyl- an engine has or how many sets of valve gears, it is a engine so long as the steam, after passing through any one cylinders, is not again used in the engine. To this class most small stationary engines, and, with a few exceptions, tives and all engines which take their steam directly from ler, and, after one expansion, exhaust it into the atmosphere a condenser. The great advantage of this type over multiple ion engines is, as their name implies, extreme simplicity nsequently, also, low first cost. On the other hand, they economical as far as steam consumption is concerned, and arge stationary and marine engines, where economy in the team is an important factor, are usually compound, triple on, or even quadruple expansion engines. The reasons latter are superior in this respect will presently appear, ie actual difference *in steam* consumption will be found *Steam Engine Economy.*"

Compound engines are those in which the steam, after d work in one cylinder or set of cylinders, called high-pres cylinders, is exhausted into another cylinder or set of cylind called low-pressure cylinders, where it is further expanded. pressures and diameters of cylinders are usually so proportic that the same amount of work is done in the high-pressure se in the low. There are many different ways of arranging the inders of compound engines. When only one crank is used the pistons are placed on the same piston rod the engine is ca a tandem compound engine, which is the simplest form, and si engines are frequently converted into tandem compound eng by simply extending the piston and valve rods and ad another cylinder of larger diameter, with suitable changes in valve gear. As usually constructed, the two valves of tan compound engines are actuated by the same valve rod, w necessitates excessively long steam passages in the high-pres cylinder, causing a considerable waste of steam. In the on the following page, which represents a tandem compound en as built by the Ball Engine Co., of Erie, Pa., this is avoide the use of two separate valve rods operated by separate eccen on opposite sides of the engine.

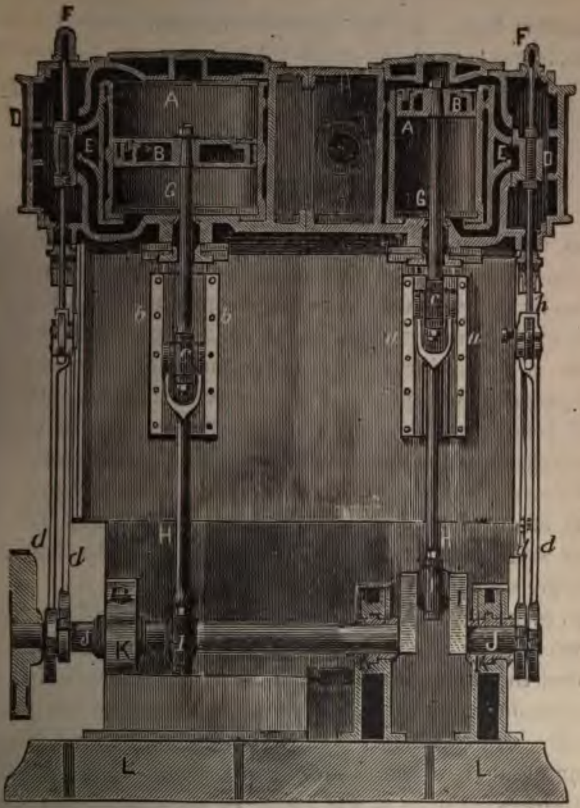
It is frequently inconvenient to use the tandem arrangeme cylinders on account of the excessive amount of space occupie the direction of the centre line of the cylinder. In such cases customary to place the cylinders side by side, with a sep crank for each cylinder. This arrangement is shown in the of the Compound Marine Engine on pp. 342 and 343. It wi observed that the cranks, while acting on the same shaft, placed at an angle relatively to each other—in this case 90 deg This arrangement of the cranks, which is necessary for ma engines, where there is no fly-wheel to steady the motion of engine, necessitates an important change in the construction o engine. In the tandem arrangement the steam when exha *from the high-pressure* cylinder is immediately admitted to *low-pressure cylinder*, both pistons being at the end of their



Section View Tandem-compound Engine. Ball Type.



Marine Compound Engine.



annexed cut represents the section through the cylinders, steam-chests, ss-heads, pillow-blocks, etc., of a Compound Marine Engine. *A, A,* ow the high- and low-pressure cylinders; *B, B,* the pistons; *G, G,* the ston-rods; *D, D,* the steam-chests; *E, E,* the exhaust cavities; *F, F,* lve-rod guides; *H, H,* connecting-rods; *I, I,* cranks; *J, J,* crank-shaft; , *K, K,* pillow-blocks; *L, L,* foundation-plate; *c, c,* cross-heads; *a, a,* *b,* cross-head-guides; *d, d, d, d,* eccentrics. The steam is admitted from e boilers to the steam-chest of the high-pressure cylinder, from which is exhausted *into the receiver* and readmitted into the low-pressure *inder, after which it escapes to the* condenser.

at the same time. In the other arrangement (called cross-co pound), however, with the cranks 90 degrees apart, the low-pressu piston is at the centre of its stroke when the exhaust is opened the high-pressure cylinder, and consequently it becomes necessa to store this steam until the low-pressure piston reaches the e of its stroke. For this purpose it is customary to employ *receiver*, which is a chamber between the cylinders of compou engines, into which the steam from the high-pressure cylinder capes, and from which it is admitted to the low-pressure cylind The receiver may be said to be the steam-drum for a low-pressu cylinder; its capacity might be infinite, except for the weight a expense it would incur. In the majority of independent co pound engines the capacity of the receiver is about equal to th of the low-pressure cylinder, though for engines in general capacity is regulated by certain attending circumstances. F very large engines two low-pressure cylinders are frequently us instead of one, in which case three separate cranks placed 1 degrees apart are used, although different angles between t cranks are sometimes employed.

The principal object of compounding engines is to secu greater economy in the use of steam, and it may be said, in ge eral, that the saving is from 10 to 20 per cent., depending on ho far the steam is expanded, the saving being the greater the high the degree of expansion. Thus in an engine with six expansio the saving due to compounding was about 12 per cent., whi with eight expansions it was about 15 per cent. The reason f this will be clear when we stop to consider why it is that co pound engines are more economical than simple engines. Su pose the steam pressure to be 120 pounds per square inch, a suppose it to be expanded in the engine to atmospheric pressu or about fifteen pounds per square inch, which would be a rat of expansion of eight. The steam when it enters the cylinder h a temperature of about 340°. As it expands the temperatu *gradually falls*, until at atmospheric pressure it is only 212 *a reduction* of 128°, or about 35 per cent. Naturally th

ılls of the cylinder are also cooled, and consequently the next
ne the steam is admitted it strikes the cold walls of the cylinder
d is partially condensed. This condensation, called *initial con-*
nsation, is an absolute waste, as no work whatever is performed
the loss of heat. The trouble is partially remedied by the use
steam jackets, but even under the most favorable circumstances
is enough to materially impair the efficiency of the engine. Now
he steam is expanded successively in two separate cylinders, it
vident that each cylinder will be subjected to only one-half the
riation in temperature, and hence the loss by initial condensa-
n is also only about one-half as great. This is the reason why
npound engines are more economical than simple engines, and
evident that the gain is proportional to the difference between
temperature of the live steam and that of the exhaust.

esides the gain in economy, compound engines have certain
ıanical advantages over simple engines. There being two
ks in compound engines (except tandem), these may be set
ny desired angle, and thus the turning effect on the shaft
more uniform; besides this the effect on the piston is very
ed. If the entire expansion takes place in a single cylinder,
is a great difference between the initial and mean pressure
e piston, whereas in the case of a compound engine these are
more nearly equal. As the engine parts have to be de-
to withstand the maximum pressure, it is evident that for
ı power these may be made lighter in the compound than
simple engine. A condenser should be used whenever pos-
th compound engines, because with a low-pressure cylinder
diameter the gain in economy is proportionally greater
loss due to initial condensation less.

e and Quadruple Expansion Engines.—When the steam
used is very high the advantages which are offered by
f two successive expansions of the steam in independent
are to be had to an even greater degree by expanding
ı successively *in three or four* independent cylinders.
ines are called respectively triple and quadruple expan-

sion engines, and the arguments which have been used in favor (compound engines apply to all multiple expansion engines.] modern steamships steam pressures of 160 pounds and over a commonly used, which means a difference of temperature, if co densing, of about 250° Fahrenheit. Such enormous differenc in temperature would involve a very material loss of heat even a compound engine, and therefore it has been found advantageo to use triple and quadruple expansion. The most common a rangement of multiple expansion engines is illustrated in tl frontispiece,* which represents the type much used in the Unit States Navy (coast line battleships Nos. 1, 2, and 3). Th engine is of the triple expansion type, with high-pressure cyli ders, 34½″, intermediate cylinder, 48″, and low-pressure cylindc 75″ in diameter, stroke 42″. The horse-power is 4500, and there a three cranks set 120 degrees apart. In some cases there are but tw cranks, the high-pressure cylinder being placed over the interm diate, the two working on one crank, while the low-pressure cyli der drives a separate crank. Various other arrangements o cylinders have been adopted, but that illustrated in the fronti piece, where each operates a separate crank, is the most commo because it gives the most uniform turning moment on the shaft.

Throttling and Automatic Cut-off Engines.

An automatic cut-off engine is any steam engine in which th distribution of steam is so controlled by the governor as to cu off the steam at any point from zero to three-quarters stroke—th cut-off taking place earlier or later to accommodate the varyin load on the engine and the pressure in the boiler, the object bein to obtain full boiler pressure at the commencement of each strok and maintain it to the point of cut-off, leaving the balance of th stroke to be completed by expansion, the speed of the engi being controlled by the cut-off and not by throttling. In engin

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'*rom the* Report of the Chief of the Bureau of Steam Engineerin *ngton, D. C.*, 1890.

of this class there is no impediment (save such as may occur at the port of entrance) to the free flow of steam from the boiler to the cylinder, the regulation being effected not by diminishing the pressure, but by cutting off in the cylinder the volume of steam necessary for each particular stroke; consequently, the only loss in pressure between the boiler and cylinder is that due to the number of bends and the length of the connecting pipe.

Although all intelligent engineers are agreed upon the superior economy of the automatic cut-off engine, few, excepting those who have had the opportunity of making a practical comparison, are aware of the great saving in the expense of fuel over that class of engines wherein the point of cut-off is invariable relative to the stroke of the piston. It is well understood, that the amount of work realized, as compared to the total theoretical work due the volume of steam expended, even in the most perfect engine, is a very small percentage of the whole energy; and it is, therefore, the more an object of interest to know precisely what the difference is between these two classes of engines in point of economy. The conditions which insure the highest grades of economy are a full port with no intervening obstructions to impede the free flow of the steam, and a rapid movement of the cut-off, or steam-valve, over the port; as mere increase in the mean effective pressure, resulting from a tardy closing of the port, represents no gain during one stroke of the piston that may be stored up and expended during the succeeding stroke; hence, any force upon the piston in excess of that required to balance the resistance will result in a diminished economy.

The economy of non-condensing engines is exactly in proportion as their average piston pressure is higher than the terminal, providing the latter does not fall below that of the atmosphere; the highest economy being attained when the stroke is commenced with full boiler pressure, and the steam quickly and completely cut off at a point in the stroke that allows the pressure to fall to, or very near, that of *the atmosphere*. The relative economy of automatic cut-off and throttling engines will be found under "Economy of Steam Engines."

Throttling engines are those in which the flow of steam from the boiler to the cylinder is regulated either by a throttle-valve, a kind of damper in the steam-pipe, which, as the speed of the engine increases, is turned, and stops off the supply of steam, or by the steam in its passage from the boiler to the cylinder oozing through the passage of some peculiar type of governor-valve. An engine controlled by any such device is in a condition somewhat like that of a horse restrained by a brake applied to the wheels of a wagon. Such relics of barbarism are fast giving place to the automatic cut-off arrangement, by which the brakes are removed from the wheels, and the bit placed in the horse's mouth, instead. Manufacturers of this class of engines claim that they give results equal to the automatic cut-off engines, which is untrue, both as to economy and close governing. With an early cut-off, which is absolutely necessary to good economy, it is simply impossible to govern the speed of throttling engines closely, with even a moderate change in load and pressure.

In the best types of throttling engines, in consequence of the peculiar construction of the governor-valve, and the tortuous passage through which the steam has to travel, the pressure in the cylinder is in many cases not more than one-half of the boiler pressure; the effect of which is, that when the work to be performed is varying in its nature, such engines increase their speed when any considerable load is thrown off, and decrease it when additional load is put on. Now, every stroke an engine makes above its regular speed is a waste of steam, and if the engine is large, or runs at a high speed, the volume of steam, and consequently of fuel, wasted will be enormous; likewise every stroke an engine makes below its ordinary speed, when work is thrown on, lessens production. The loss of one revolution in ten diminishes the productive capacity of every machine driven by the engine 10 per *cent.; in short,* the loss of one revolution in ten diminishes the *productive capacity* of the whole factory 10 per cent.; while the ense of conducting the whole business, rent, wages, insurance, ., continues the same as if everything was in uniform motion. variation of one revolution in ten is quite common in throttling ines.

Steam Engine Cut-offs.

Most of the engines which will be described in Chapter XX. ong to the automatic cut-off type; in fact, this class of engines udes most of the stationary engines of to-day. Throttling ines are occasionally used for small powers and uniform loads, account of their simplicity. The vertical engine described in beginning of this chapter, which is one built by the New York ity Steam Power Company, is a good representative of the dern throttling engine, and any further description of other es would be simply a repetition.

Stationary, Marine, and Locomotive Engines.

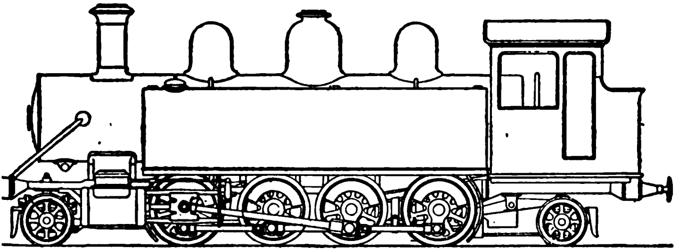
The classification of steam engines into stationary, marine, and motive is rather an unsatisfactory one, because in many cases re is really no difference in the design of these engines. A dern marine or a locomotive engine could be used equally well many purposes to which stationary engines are applied; in , the marine type of engines frequently is used in large power nts, while there is practically no difference between a locomo- engine and a stationary hoisting engine except in the mount- of the parts. Nevertheless, marine and locomotive engines e certain characteristics which distinguish them from ordi- ry stationary engines, and these will be briefly pointed out.

Marine Engine.—The term marine engine is in very common but it has no definite meaning, as it may be either condensing non-condensing, vertical, horizontal, or inclined, simple or pound. The only reason that can be assigned for designating marine engine is that it was designed to be used on steam- s. *A marine engine, properly* speaking, is an engine designed *cupy a certain space on a* vessel, and be capable of developing a certain amount of power. The most desirable marine engines are those that develop the greatest amount of power with a given area of piston and steam pressure, and that occupy the least space. The vertical engine is more in favor with marine engineers, as it possesses many advantages over any other design. This perhaps arises from the fact that it occupies less floor space; that it is more compact and less liable to spring than an engine of any other design; and that the weight is against the lifting-force of the reciprocating and revolving mechanism; also that, in consequence of the housing and pillow-block bearings being in one piece, they are less liable to get out of line than those of any other arrangement; and that they afford better facilities for a direct connection with the propeller shaft than any other. Marine engines are mostly condensing because of the abundant available water supply, and they are usually compound, triple, or quadruple expansion engines, because of the high pressures which it has been found necessary to employ, and also because, in the absence of a fly-wheel, several cranks, set at different angles, produce a more uniform rotation than a single crank.

The government of the speed of marine engines is usually still by means of the throttle-valve, but inasmuch as this is rarely called upon to act, except in very rough weather, the losses in economy are not very great. The throttle-valves of marine engines are usually very large, and consequently it would not be feasible to arrange the governor so as to act upon it directly, hence steam governors are generally used, at least for the larger engines. These consist of an ordinary centrifugal governor, which operates the slide valve of a small steam cylinder, and this in turn opens or closes the main throttle valve as the varying conditions of load may require.

The frontispiece shows a modern triple expansion condensing marine engine. This engine, which has already been referred to above, is one of a pair of engines designed by the United States *Bureau of Steam* Engineering for coast line battleships of 9000 *tons displacement*, cruising at a speed of fifteen knots. Under nary conditions they develop 4000 horse-power each, and 4500 e-power when forced. The diameters of the cylinders are ectively 34½, 48, and 75 inches, and the stroke 42 inches; the d of the piston is 900 feet per minute, corresponding to 129 lutions of the shaft, and the steam pressure 160 pounds per re inch. The slide valves are of the piston type—that is, cyl- ical instead of flat, there being one valve for the high press- two for the intermediate, and four for the low-pressure cylin- This is necessary, because as the steam expands its vol- increases, requiring greater area for the steam passages and me for the steam chests. The framing of the engine consists olumns resting on cast-steel bed-plates, and the shaft, cranks, , etc., are of forged steel. The condensers for these engines be illustrated and described under that heading, while a ription of the auxiliary boilers will be found on page 173.

ocomotive engines, as already stated, differ from stationary nes mainly in their details of construction and the method of nting the parts. A locomotive engine consists essentially of independent steam engines working on a common set of driv- wheels, by means of cranks set 90 degrees apart, the number



riving-wheels used depending on the class of service. In the cut, ch represents a side-view elevation of an "eight-coupled, ble-ender tank locomotive," as built by the Baldwin Locomo- Works, *there are eight driving* wheels, four on each side, *led together and to a* common connecting rod. The valve motion in this engine and in most American locomotives consis of a pair of eccentrics and a link, actuating an ordinary flat slid valve for each engine, the cut-off being varied by means of th link. (For description see Valves and Valve Gears.) Locomotives are not provided with governors, for various reasons, th speed being variable and under constant control of the eng neer. It may be varied either by the throttle or the cut-o but preferably the latter, because more economical in the u of steam.

In estimating the power of a locomotive, the term horse-pow is not generally used, as the difference between a stationary stea engine and a locomotive is, that while the stationary engine rai its load, or overcomes any directly opposing resistance with effect due to its capacity of cylinder, the load of a locomotive drawn, and its resistance must be adapted to the simple adhesio of the engine, which is the measure of friction between the tir of the driving-wheels and the surface of the rails.

The power of the locomotive is estimated in the moving for at the tread of the tires. It is called the tractive force, and equivalent to the load the locomotive could raise out of a pit b means of a rope passed over a pulley and attached to the dra bar of the engine. The adhesive power of a locomotive is th power of the engine derived from the weight on its driving wheels, and their friction or adhesion to the rails.

If the wheels of a locomotive were geared into toothed rail its power would be measured by the force with which its whe [illegible] force which, if applied at the ri [illegible] them from turning. But if th [illegible] and slipped in turning, a part [illegible] the effective power of the engi [illegible] its driving-wheels. He [illegible] adhesive power" mean [illegible] and the progressive power of th engine.

Single- and Double-acting Engines.

fference between single- and double-acting steam engines e former admit steam to only one side of the piston, the ng open to the atmosphere, while in the latter both ends linder are closed and steam is admitted at either end of n. Obviously, of two engines, the one single- and the ıble-acting, having the same diameter of cylinder and orking under the same boiler pressure and at the same ɘ double-acting engine will develop twice as much power ıgle-acting. Consequently it may be said at once that r is the less economical as far as first cost is concerned. ıe further disadvantage that, on the return stroke, ad- cannot be taken of the cushioning action of the steam for the reciprocating parts to rest; hence, unless some other is made for accomplishing this end, it will not operate ıly as the double-acting engine. On the other hand, it in mechanical advantages; for example, the cross-head ing-box may be omitted and a single rod used to replace n and connecting rods. The vast majority of steam however, are double-acting, although a few of the single- ıgines, notably the Westinghouse and the Willans, have y successful. These will be described in Chapter XX.

Reciprocating and Rotary Engines.

at has thus far been said in regard to steam engines ıg the definition) applies only to reciprocating engines— hose in which the force of the steam is used to produce a ıting motion of the piston, which, by means of other parts ıgine, is converted into a rotary motion.

rotary engine there is no reciprocating motion whatever, ɜ of the steam being used to produce at once a motion of Rotary engines are not economical in the use of steam, ile a great many different types have been designed, they little used.

Economy of Steam Engines.

The principal reason which has impelled engineers to duce new designs of steam engines was to attain additional econ in the use of fuel, and yet with all that has been done in direction since the time of James Watt, the steam engine is st very wasteful machine, and only a small percentage of the en contained in the fuel is actually converted by the steam en into useful work. There are certain losses of energy which il hitherto been impossible to avoid, and so long as these mu incurred so long will the process of transforming the latent en of coal into mechanical work by means of the steam engine wasteful one.

Pounds of coal consumed in evaporating 1 pound of water at 200° F., into steam at 80 pounds pressure (in the best boilers).........	.1	
Pounds of water consumed per horse-power in non-condensing, high-speed steam engines, about..	30	
Pounds of coal consumed in evaporating 30 pounds of water at 200° F. into steam at 80 pounds pressure (equivalent to the work of one horse-power hour) = 30 × .1 = ...	3	
Pounds of coal consumed per hour for 100 horse-power = 100 × 3 = ...	300	
Heat units contained in 1 pound of anthracite coal, about..	12,000	
Heat units contained in all of the coal consumed each hour = 12,000 × 300..............	3,600,000	
Maximum (theoretical) work which can be done by one heat unit, in foot-pounds........	778	
Foot-pounds of work stored in all of the coal consumed each hour = 778 × 3,600,000 =		2,800,0
Foot-pounds of work done per hour by each (indicated) horse-power 33,000 × 60.........	1,980,000	
Foot-pounds of work done per hour by 100 indicated horse-power..............................	198,000,000	
Losses in overcoming friction of engine about 10 per cent..	19,800,000	
Total foot-pounds of useful work at engine shaft per hour..	....	172,0
Foot pounds lost per hour........................	....	1,628,0
Percentage of useful work about................	....	6¾ p.
" lost "	....	94¼

s an example of the losses which occur in the steam-engine,
e the case of a modern water or fire tube boiler and a high-
ed, non-condensing engine, a combination which can be found
almost every isolated plant for electric lighting. Engines of
class usually operate under a steam pressure of 80 pounds,
require about 30 pounds of water per indicated horse-power-
r. Suppose the plant under consideration has a capacity of
0 incandescent lights, and that an engine of 100 indicated
se-power is used. The preceding tabular statement shows how
h of the energy contained in the coal is actually transformed
useful work at the shaft of the engine under favorable condi-
s.

hat is, of the total energy contained in the fuel less than 7 per
t. is available at the shaft of the engine. The principal reason
this is that so much heat or energy is absorbed in changing
water into steam, and in the non-condensing engine this is
rely lost. Of course the steam, after leaving the engines, is
uently used for other purposes, such as heating, etc., in which
much of the heat it contains is utilized. Besides, this type
ngine is one of the least economical in use at the present day.
figures given in the table on page 357 show the comparative
omy of different types of steam engine, and by a calculation
ilar to the above the percentage of energy utilized by each
be easily ascertained.

large part of this loss of energy occurs in the steam generator
oiler. It is due partly to the high temperature at which the
es escape from the chimney, which is necessary for the produc-
of the draught, as explained above, and partly to the excess
air over and above that necessary for complete combustion of
fuel. There is rarely more than 10 to 12 per cent. of carbonic
l in the flue gases, and this means that there is more air sup-
ed than is necessary for the combustion of the fuel, and in
ting this excess to the temperature of the products of com-
tion a loss of *energy equal to* about 16 per cent. of the
l fuel consumed is incurred. Additionally there are losses

due to radiation, to leakage, and to the heat carried away in the ashes.

The losses in the engine proper are due mainly to the presence of moisture in the steam cylinder. Nearly all of this moisture, which is either carried into the cylinder with the steam from the boiler, or is produced by condensation on the cylinder walls or in the steam passages, is re-evaporated during the expansion and exhaust periods, and in re-evaporating, abstracts heat from the steam. Very little of the heat which is used in this way is returned to the engine as useful work, and consequently the presence of moisture may be said to rob the engine of an amount of useful energy proportional to the heat required for its evaporation. It is therefore of the utmost importance to the economy of steam engines to prevent the entrance of water into the cylinder, or its formation by condensation on the walls of the cylinder and in the passages.

The moisture which enters the cylinder with the steam is not properly chargeable to the engine. Dry steam may be had at the throttle of the engine by the use of properly designed boilers, steam separators, and non-conducting pipe covering. The production of moisture in the cylinder, however, is due to the design of the engine and to the conditions under which it operates. As an example, consider a plain slide valve engine, and suppose the steam is admitted under a pressure of 100 pounds per square inch, is cut off early in the stroke, expands, and is exhausted against the pressure of the atmosphere. The entering steam has a temperature of about 338° F., and as the steam expands this is gradually reduced, until at the end of the stroke, when the exhaust begins, the temperature is only 212° F., and this is maintained during the entire return stroke. Furthermore heat is continually radiated to the surrounding atmosphere, and consequently by the time steam is again admitted the walls of the cylinder and the steam passages have been so much reduced in temperature that a very considerable amount of heat must be abstracted from the steam to again raise the temperature of the walls. This will ritably cause condensation of a portion of the steam, which will e repeated at every stroke, and result in a material reduction in e efficiency of the engine.

The condensation of steam in the cylinder, called initial con- nsation, is greater, the greater the surface exposed for a given ight of steam passing through the engine, and consequently it not as great proportionally in large engines as in small ones. viously, also, it is proportional to the range of temperature to ich the cylinder is exposed, and it is for this reason that multi- e expansion engines are more economical. This has already en explained in discussing the latter type of engine above. As as the condensation in the steam passages is concerned, it has en found that this could be almost entirely eliminated by clos- the exhaust before the end of the stroke, so as to compress the am and thus raise the temperature of the walls and passages, more effectually, by providing separate passages for admission d exhaust. This is the reason why the so-called Four Valve d the Corliss types of engine are more economical than those in

STEAM CONSUMPTION OF DIFFERENT TYPES OF ENGINES.

Description of Engine.	Horse-power.	Steam Pressure.	Water per 1 H. P. per hour.	
			Non-Condensing.	Condensing.
ain Slide Valve with long troke. Cut-off about ⅝...	25–100	75–80	40-50 lbs.	30-40
tomatic, High Speed Single Valve. Cut-off ¼...	50–150	75–80	25–35	20-25
tomatic, Four Valve, and Corliss High Piston Speed. Cut-off about ⅕...	50–500	75–100	24–32	18–24
mpound Automatic High Speed. Single valve......	200–500	110–120	22–30	16–24
mpound Automatic, Four Valve and Corliss High Piston Speed...............	*400 or over*	110–120	20–27	13–20
ple Expansion............	*500 or over*	120–160	20–27	12¾–18

which the same passages are used for both admission and exhaus The losses of heat due to radiation may be effectually prevente by surrounding the cylinder with non-conducting material. Th use of the steam jacket (see page 363) is also frequently ver effective in reducing the losses due to initial condensation.

The measure of the economy of steam engines is the amoun of water (or steam) required per hour to produce one indicate horse-power. This varies in different types from about 14 poun to upward of 60 pounds. The preceding tabular statement giv average values of the most common types, and from these t relative advantages of high pressures, compounding, condensin etc., may be observed.

CHAPTER XVII.

STEAM ENGINE PARTS.

The present chapter will be devoted to a general considerati of the functions and design of the different parts of the ste engine as enumerated in the beginning of the previous chapt excepting "Valves and Valve Gears" and "Governors," whi will be taken up in Chapters XVIII. and XIX. respectively. T different designs used in the construction of steam engine parts, different makers, will be found in Chapter XX.

Bed-Plates and Housings.

The bed-plate is that part of a steam-engine which forms t connection between the cylinder and the main pillow-block crank-shaft, and, in many instances, constitutes the support which they rest. They embrace a great variety of shapes a forms, such as the box side bed-plate, girder-frame, etc., whi were all doubtless designed to meet some peculiar requireme and for each of which special advantages are claimed, the gird frame being in most favor with modern engineers. This is part due to the fact, that the necessary rigidity can be obt less metal than in any other form, and that the strength can ore equally distributed in the line of the strain, and above below it. Bed-plates are subjected to transverse in addition sile and compression strains.

designing a girder-frame, if it is to be supported only ends, due allowance must be made for transverse strains the thrust of the connecting-rod. The amount of this may be found by dividing the greatest pressure to which ston may be subjected at mid-stroke by the quotient ob- by dividing the connecting-rod by the crank. Thus, sup- he area of the piston is 200 sq. inches, and it is desired to mple strength for, say 80 lbs. of steam at mid-stroke; 80 = 16,000 lbs., the force on the piston. Then suppose otient obtained by dividing the connecting-rod by the crank 16,000 ÷ 5 = 3200 lbs., the pressure on the slides at mid-

When the engine runs over, that is, when the top of the eel runs from the cylinder, the weight of the cross-head, alf the weight of the connecting- and piston-rods, must be to this, and deducted when the motion is in the opposite on.

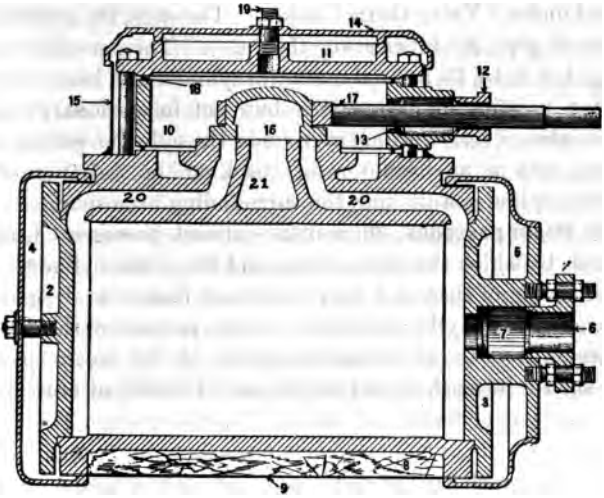
Isings are the upright frames of vertical engines on which linders rest and which contain the main bearings of the Their design depends entirely on the nature of the engine, e proportions are largely a question of experience. They e made strong enough to support the weight of the engine and of sufficient rigidity to prevent vibration, but no defi- les can be given as to their proportions.

h bed-plates and housings should be made as heavy as pos- ithout being wasteful of material, and, it may be said in l, that, other things being equal, the running of an engine the more satisfactory the heavier the framework.

Steam-Cylinders.

cylinder *is one of the* most important as well as the most *ve parts of a* steam-engine; it must be made of iron pos sessing the qualities of hardness and toughness, be moulded and cast with great care, and bored with great accuracy. Cylinders, from the moment they are put into use, have a tendency to wear oblong, also to wear larger in some places than others. This involves the necessity of reboring them, which is one of the largest items of expense incurred in the repairs of a steam-engine.

There are certain peculiarities connected with the wear of steam-cylinders upon which engineers have hitherto been unable to agree, among which is, why the cylinders of different engines of the same size, design, and manufacture, and under the same conditions, wear in opposite directions. The cylinders of some horizontal engines wear more on the lower than on the upper side, while others of the same size and build wear more on the sides opposite the ports, and others on the sides next the ports. Nor is it always the largest cylinders and heaviest pistons that wear most on the lower side of the cylinder. The same peculiarities hold good in relation to vertical engines. On some lines of ocean steamers, where four or five of the engines were built by the same manufacturing firm, and whose design, quality of material, character of workmanship were intended to be as much alike in every respect as it was possible to make them, it was found on examination that the cylinders of all were worn oblong—some in the middle, others at both ends, and others still at only one end. It is a general impression among engineers that the cylinders of very large horizontal engines are more liable to wear oblong than those of vertical engines of the same bore; but experience and observation have proved this to be a mistaken idea. The trouble is frequently due to imperfect alignment, and it is difficult to imagine why an engine piston should exert any pressure against the cylinder walls, other than that due to gravity, when all of the reciprocating parts are perfectly true with the centre line of the engine and with each other. Care should be taken to see that this is the case, and also that the packing is placed with uniform thickness ud the piston rod, as any material inequality may throw the out of alignment. The wear which would occur on the om of the cylinders of large horizontal engines on account of weight of the piston is frequently avoided by extending the through a stuffing-box in the outer cylinder head.



Steam Cylinder.

he **above cut,** which represents a steam engine cylinder as d on a modern locomotive,* shows all of the essential parts of eam cylinder. 1 represents the cylinder proper, 2 and 3 the ds, which are held in position by means of bolts. The back nder head, 3, has a stuffing-box, into which fits the gland 6. will be observed that the hole in the stuffing-box is slightly er at the outside. This is for the packing around the piston , which makes it tight, the gland 6 being forced inward until the king entirely fills the space provided for it. A similar stuffing- and gland, 12, is provided for the valve rod, 17. The steam st 10 is held in position by the cover, 11, which is bolted to

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From an "Illustrated Catalogue of Narrow Gauge Locomotives," Bald-*Locomotive Works, Philadelphia.*

the cylinder casting, although a more usual construction cast the cylinder and steam chest in one piece and bolt the c to the latter. The slide valve 16 is actuated by means of valve rod 17, and admits steam behind the piston, as will b plained under "Valve Gears" below. The stem, 19, is for at ing an oil pipe for lubricating the valve. The cut also sho casing, 4, 5, 9, 14, 15, around the entire cylinder and heads, whi common practice in locomotives but not in stationary en The wooden cover, 8, which surrounds the cylinder proper, c lagging, acts as an insulator for checking the radiation of from the cylinder walls into the surrounding atmosphere.

The steam passages, 20, and the exhaust passages, 21, a channels by which the steam enters and leaves the cylinder. proportioning of these is a very important feature in designi engine, and it may be said that a large portion of the los engines is due to an incorrect design of the steam pas They should be as short as possible and of sufficient cross s to prevent any reduction of pressure in the steam. The g rule is to provide one square inch cross section of steam po every square inch area of piston and 100 feet of piston spee second. Hence, to determine whether the steam passage properly proportioned,

Rule.—Multiply the area of the piston in square inches b piston speed in feet per minute and divide the product by The result will be the proper cross section of the steam pass square inches.

The term clearance is understood by engineers to mea unoccupied space between the piston- and cylinder-heads the crank is at the dead-centre; but it also applies to the between the cylinder and the face of the valve or valves, slide or poppet. The amount of clearance of any engine its economy; and if the clearance is small, the engine w more economical than if large; a certain amount is an ab necessity. It is, therefore, an object of importance, in poi economy, to have the valve-face as near the base of the c

ssible. In this lies one of the most important features of that
of engines known as four-valve engines as well as those of
orliss type. The clearance varies with different builders,
n different engines from 1½ to 10 per cent. of the cubic con-
of the cylinder.

e clearance is often as high as fifteen per cent., in some old-
oned long stroke, slide-valve engines. This arose from a mis-
ption, at the time they were designed, of the waste the large
ance would occasion, and is, perhaps, in many instances, due
caprice of the inventor of some patent piston, who made his
-rings of less depth than the original designs, thus increasing
ace between the piston- and cylinder-heads, when the crank
the dead-centre. There are even cases to be met with, where
ld fashioned, hemp-packed piston has been replaced by me-
packing of not more than half its depth, without any means
taken to fill up the spaces at each end of the cylinder.
providing that the clearance is fifteen per cent. of the cubic
nts of the cylinder, and that the engine makes from one
red and fifty to two hundred strokes per minute for ten
, it may easily be seen how enormous the waste must be.
uantity of fuel that might be saved by replacing such an
e by one in which the clearance would be reduced to a mini-
, would more than pay for the latter in five years. Persons
oying steam-power, or intending to purchase steam-engines,
d pay attention to the foregoing fact.

the clearance space is generally irregular in form, particu-
in slide-valve engines, it is somewhat difficult to calculate
xact cubic space. The most accurate method of ascertaining
xact amount of the clearance is to place the crank at the
-centre, and fill the space with water up to the face of the
(the quantity of water being previously weighed or meas-
). Then deduct the amount remaining in the vessel from the
e, and the remainder will be the quantity contained in the
ance in cubic *inches or gallons*, as the case may be.

keting is a term *applied* to a method which is adopted in many of the larger engines, working at high pressures to reduce the initial condensation in steam cylinders. A steam jacket consists of an annular space around the cylinder, which is filled with live steam from the boilers.

The Piston and Piston Rod.

The piston is that part of the steam engine which first receives and transmits the pressure of the steam to the other mechanism, which, in a sense, is subsidiary to it. It consists of an iron disc fitting into the cylinder, and the nature of the work which it has to perform requires that it should be strong, durable, light in weight, accessible, and, above all, that it should maintain a steam-tight contact with the cylinder walls. It is impossible to give any rule for calculating the thickness of pistons, as different conditions require different designs. If it is not steam-tight, there will be a continual leakage of steam, causing a serious loss in the economy of the engine. This is one of the most common losses in a steam engine and one which must be carefully watched, not only by builders of engines, but also by those who have charge of running them. The usual method of keeping steam pistons tight is to provide them with one or more cast-iron rings which fit into grooves cut into the circumference of the piston. The piston is first turned to a diameter slightly smaller than that of the interior of the cylinder. The piston rings are of cast-iron and slightly larger than the diameter of the cylinder. After they have been turned to a smooth finish on the outside a piece of sufficient width is cut off the circumference of the ring, and it is then placed in the groove of the piston and sprung into the cylinder. When in place the tendency of the rings is to spring outward, and in this way a steam-tight joint is effected.

A great many different styles of pistons have been devised; in fact, different kinds of engines require different kinds of pistons. *Those illustrated* in the accompanying cuts represent four *different methods of* packing employed by the Baldwin Locomotive *orks. In Fig.* 1 the method referred to above is used—that the packing consists merely of cast-iron spring rings, 8, which press against the cylinder by virtue of their elasticity. In this design the end of the piston-rod is slightly tapered. It is threaded at the extreme end, where it projects through the piston, and is held in place by a collar and nut. In Fig. 2 the packing consists of brass and composition rings, 10, held in place by means of the flat plate 2, called the follower, and pressed outward by three flat springs, 11. The follower is used so that the rings may be taken out and adjusted without disturbing the piston. The piston is secured to the rod by means of the key 6, and the follower is secured to the body of the piston by means of tap bolts, 3, and brass nuts, 4. In Fig. 3 the packing consists of a cast-iron tee ring, 9, and spring rings, 8. It is virtually a combination of the first and second methods, embodying the use of cast-iron spring rings, together with the advantages derived from the use of the follower, namely, accessibility for removing the packing without disturbing the piston proper. The same design is used in Fig. 4, except that the rings, 8, instead of being spring rings, have independent steel wire springs 13, *placed between* the tee ring and the piston ring *in order to force the latter* outward against the cylinder.

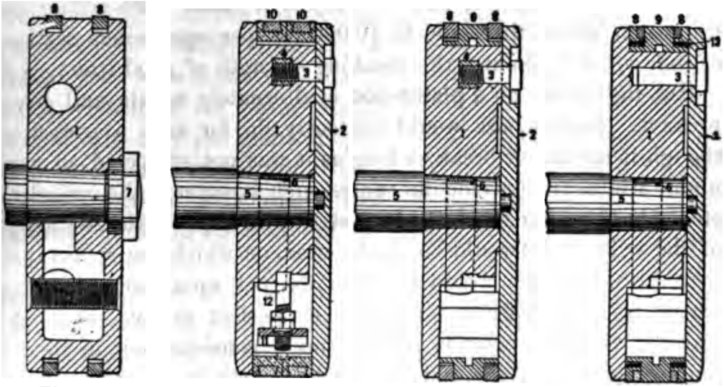

Fig. 1. Fig. 2. Fig. 3. Fig. 4.

Pistons.

Piston-Rods.

The diameter of piston-rods varies with different builders, range being between $\frac{1}{6}$ and $\frac{1}{10}$ the diameter of the cylinder, cording to their length and probable maximum pressure. high-pressure piston-rods of the American line of steamships about $\frac{1}{7}$ the diameter of the cylinders, and the low-pressure al $\frac{1}{16}$. The piston-rod of the Centennial Corliss Engine was al $\frac{1}{6}$ the diameter of the cylinder. A rod $\frac{1}{10}$ the diameter woul $\frac{1}{100}$ the area of piston; and if 100 lbs. of steam were actin the piston, the strain would be 10,000 lbs. per square-inch se of rod, which is about $\frac{1}{6}$ the breaking strength of good iron.

But the strain on a piston-rod is alternately tensile and pressive. Such a size would evidently do for such a pres though it might not break so long as it was not subjected to undue strains from accidental causes, such as water in the cyli etc. On the other hand, the largest size in use — $\frac{1}{6}$ the dian of the cylinder — would be $\frac{1}{36}$ the area, on which the strain to 100 lbs. of steam would be 3600 lbs. per square-inch sec which is fairly within the limits of perfect safety. But pressure on the piston is not the main consideration in d mining the size of the rod, as accidental strains, to which liable to be subjected, must be adequately provided for. Son these strains bear no relation to the steam pressure, so tha diameter of the piston should be made the main factor i termining the size of the rod. Bourne's rule is to *multipl* diameter of the cylinder in inches by the square root o pressure on the piston in pounds per square inch, and *d* the product by 50. The quotient is the size of the piston-ro

Piston-rods may be smaller in diameter than the foregoi is of steel, and if they possess sufficient rigidity and str that all strains to which they may be exposed, and at the have less friction, do more service, with less liability to turning, while the difference in first cost wou that of fitting about the same.

Connecting-Rod, and Crank Connections.

ry generally prevails among engineers that the
team-engine travels
part of the stroke
ier. This is evident-
The crank travels
peed throughout its
t the piston travels
e one-half its stroke
If the connecting-
efinitely long, or a
re substituted for it,
of the piston would
by the crank alone;
id-travel would cor-
ly with the corre-
s in the travel of the
piston would occupy
ion at the first and
ach stroke. But in
the distorting action
ting-rod, the piston
during the half of
hest from the crank,
tly, when the crank
f mid-travel, that is,
rpendicular to the
e cylinder, the piston
rank than its point
y an amount which
r with the length of
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fference between the
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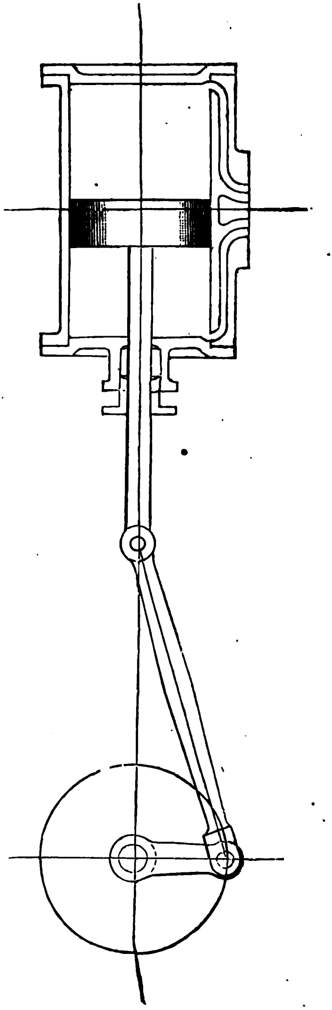
ngle formed by the



connecting rod, the crank and the distance between the cross-head pin and the shaft when the crank is perpendicular to the centre line of the engine cylinder.

Rule for finding the distance the piston is ahead of its central position in the cylinder on the forward stroke, and also the distance which it lags behind on the backward stroke when the crank is in the central position.

Subtract the square of the length of the crank from the square of the length of the connecting-rod; find the square root of the difference or remainder, and subtract it from the length of the connecting-rod. The remainder will be the variation of the piston from a central position when the crank is at right angles to the centre line of the engine.

Example.—Length of crank, 12 in.
Length of connecting-rod, 72 "

Then $72^2 = 5184$ in.
$12^2 = \underline{\ 144}$ "
Difference $= 5040$ "

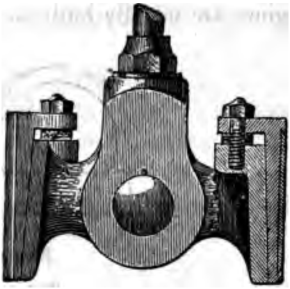
$\sqrt{5040} = 70{\cdot}992$ in.; and
72
$\underline{70{\cdot}992}$
1·008, which is the variation in inches.

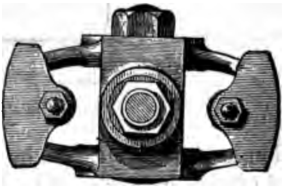
The connecting rod is usually made from four to eight times as long as the crank—that is, two to four times the length of the stroke. Long connecting rods have many advantages, but the longer they are the greater must be their thickness, consequently it may be said that short connecting rods are more economical in the use of material. The usual length for high-speed engines is about five times the length of the crank.

The Cross-head.

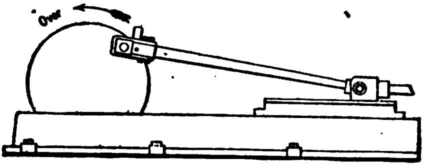
The cross-head is that part of the engine which, moving *between guides,* preserves the rectilinear motion of the piston-r

1 at the same time supplies a bearing, called the wrist-pin or ss-head pin, for the rocking motion one end of the connecting-rod. The sign and proportions of the cross-ad are largely a matter of experice and taste, although the areas of slides, if not carefully calculated the pressure to which they are subcted, are liable to heat. The acmpanying cut shows a simple form cross-head, being that used in the rtical engines built by the New ork Safety Steam Power Company. will be seen from the cut, it has justable gibs on either side, by ans of which and the screw bolts own, any wear in the slides may be sily taken up. Cross-heads may made of cast iron, wrought iron, or el, but the latter material is the st common at the present day on account of its lightness for a ren strength. The area of the wearing surface or slides dends on the pressure to which they are subjected. In a horizon engine, if it "throws over," all of the wear comes on the lower de; while, if the engine "throws under," the reverse is the case. is should be taken into account in proportioning the slides, ich should be on a basis of from fifty to eighty pounds per uare inch of surface.

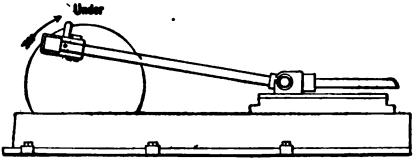




The difference between throwing over and under may be exined as follows: An engine throws over when the crank-pin verses the upper portion of its travel while the piston is moving ward the main shaft and throws under when the crank-pin verses the lower portion of its travel while the piston is moving ward the *main shaft. This is* illustrated in the following cuts, *which the arrows indicate* the direction of motion. A little study of these cuts will show that in the first case the stre slides is always downward, while in the second it is upwai gines are usually built to throw over, except when the t



Engine throwing over.



Engine throwing under.

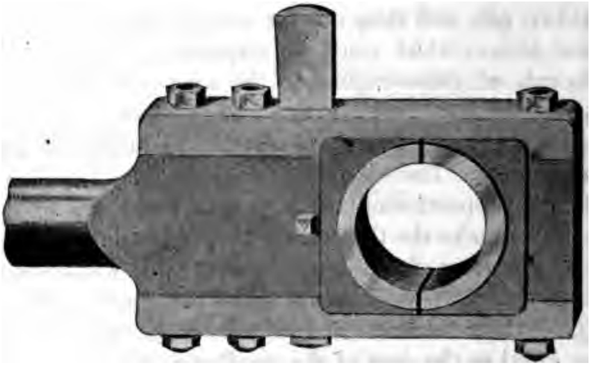
sion is such that the tight side of the belt would come on which is never advisable.

The Connecting Rod.

The connecting rod is a rod or link by means of wh the crank the reciprocating motion of the piston and cı is converted into the rotary motion of the shaft. As stated, it has a bearing at one end on the crosshead-pin, the other it engages the crank-pin. The connecting rod be made as light as possible, and it is consequently usua structed of steel, which for a given strength is lighter tha cast or wrought iron. It is usually made taper, with the cross section at the cylinder end, as this form is best sı resist the peculiar bending stresses to which connecting ı subjected. The cross-section is generally rectangular, *frequently* circular and sometimes girder-shaped. The (*'ecting* rods are of various designs. The bearings ead and crank-pin are usually made of brass or of some ction metal. These bearings, called brasses, are held to the ds of the rod by means of straps, and the wear is taken up s and gibs.

key, gib, and strap are the most simple and effective me- l devices which could be employed for securing the con- -rods of steam-engines to the wrist- and crank-pins, and up the lost motion in the boxes, as they possess sufficient h without extra weight of material, and facilitate quick and justment. There is quite a wide difference of opinion among s in proportioning the keys, gibs, and straps of their en- Some make the thickness of both straps on the connecting- he diameter of the crank-pin, and their width about ¾ the of the pin; while others make the width of their straps imes their thickness, and the area of the cross-section at the equal to the area of the smallest part of the connecting- hile others, still, make them equal in strength to the weakest n the piston-rod, which they undoubtedly should be in any It has been customary, heretofore, to make straps thinner yoke than at the mortise; but this has been partly aban- as the amount of material saved was insignificant, while ra work was considerable. The depth of the gib and key ood engine is generally about three times their thickness, e taper at about 1 in ten; though it ranges all the way he latter to 1 in 24, 1 in 15 being about the average. It is ary in some instances, as in the case of marine engines, tives, and other fast-running engines, to pass a bolt, and in ases two, through the stub-end and straps, as a precaution accidents; the holes in the straps being the exact size of t, while those in the stub are slotted, for the purpose of ing of adjustment by the key and gib.

accompanying cut represents a simple and good design of ting-rod end. In this style, which is that used in the *Engine, the strap is made* in three pieces which are held *r by bolts as shown.* The method of taking up the wear on the brasses and the different parts of the end will be cl from the cut without further explanation. When the crossh is of the type illustrated in the preceding paragraph one end



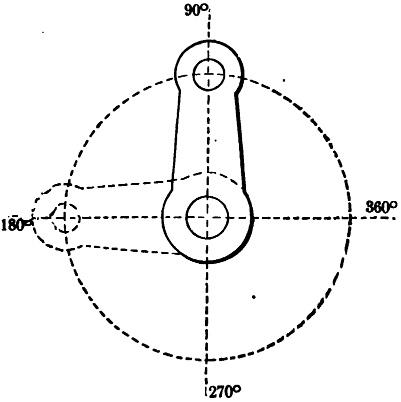
the connecting rod is forked, which virtually means a double of straps, brasses, and gibs.

The Crank.

A crank is a simple lever, at one end of which acts the st pressure which is transmitted to it by the reciprocating p while the other is secured to the main shaft of the engine. I the final link in the transformation of reciprocating into rotary tion.

The generally prevalent idea among mechanics that the an actual loss of power in the use of the crank, has stimul inventors to substitute for it a device that would utilize all power exerted against the piston without loss. As a result, U. S. Patent-Office, as well as those of the different countri Europe, are crowded with arrangements intended to supers the crank; the most popular, and consequently the most quently resorted to, being the rotary engine, in which the effe of the steam would be constant, while in the case of the intermittent; but, so far, no rotary arrangement has ever able to compete, in point of economy, with the reciprocating e.

ictly speaking, there is no loss of power in the use of the , as, while there is a great variation in the power a given pressure will exert at ent points of the stroke, tal power at the crank g one revolution of the e is the same as that e piston during two es, except for the losses iction, which in a well- engine are not great. equality in the work at iston and at the crank- ill be easily understood an example. Suppose iston has an area of square inches and the steam pressure is 100 pounds per e inch, while the stroke is 24 inches. The total pressure on iston is 100 × 100 = 10,000 pounds, and since the stroke is 2 he work done during each stroke is 2 × 10,000 = 20,000 foot ds, and during each revolution 2 × 20,000 = 40,000 foot ds. Now, at the crank-pin the force is not always in the direction. Its direction is in the line of the connecting-rod, consequently the effort to turn the crank is not always the . At the beginning of the stroke, for example, there is no ency whatever to turn the crank, the total pressure being ted against the main bearings, and if it were not for the fly- l the engine would come to rest at the beginning and end of stroke. As the stroke advances, however, the turning effort ases, and when the connecting rod is perpendicular to the k, which is *near the middle of* the stroke, the total force of *team is utilized in turning* the crank, after which the turning

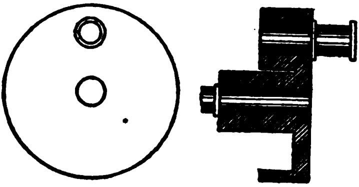


effort again decreases and disappears entirely at the end of t stroke. The force at the crank-pin may in fact be considered made up of two forces, the one acting in the direction of the cra and tending to produce pressure on the bearings, and the ot acting in a direction perpendicular to the crank and tending produce rotation, the resultant of the two being at all times eq to or nearly equal to the total pressure on the piston. Now will be remembered that work was defined as the product force and the distance through which it acts, hence it follows th since that part of the force on the crank-pin, which is exerted the direction of the crank does not produce any motion b simply pressure; it does no work, and hence all of the work done by the other part, namely, that which is exerted in a dire tion perpendicular to that of the crank. Therefore, since there h been no work lost except that of friction, the work at the cran pin must be equal to that at the piston. Again, it may be show by mathematics that the average value of the turning force at th crank-pin during one entire revolution is equal to the total pres ure on the piston multiplied by the number .6367, hence, takin the figures given in the example above, the average turning forc during each revolution would be 10,000 × .6367=6367 pound Now, since the length of the crank is one-half the length of th stroke, or in this case one foot, the crank-pin will travel a di tance equal to 2 × 3.1416=6.2832 feet per revolution. Durin this time the average turning force is 6367 pounds, hence th work done in turning the crank is

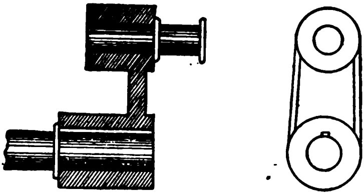
6367 × 6.2832=40,000 foot pounds,

which is the same as the work done on the piston, as found abov Hence it will be clear that there is no work lost by the cran except the friction at the bearings.

Cranks are made of cast iron, wrought iron, or steel. Th former material is used only in the rougher forms of engines an should be avoided, as it is liable to contain blow holes and oth hidden defects. The length of the crank is the distance from t centre of the pin to the centre of the shaft and is equal to e length of the stroke. The boss of the crank is that part iich the shaft is inserted, and which butts the main-bearing. In common practice th, when of cast-iron, is about twice the er of the crank-shaft journal, and the at the pin is generally about twice the er of the pin. The section of the crank n the shaft and the pin is termed the *web;* a is generally equal to that of the crank- When the crank is round it is called a plate or disc. The only advantage that cular possesses over the ordinary form is affords better facilities for balancing.

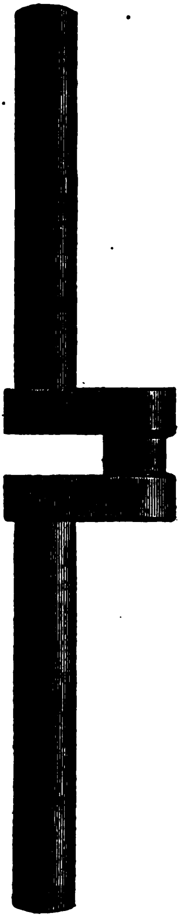


Disc Crank.



Side Crank.

above cuts represent the three styles of most commonly used. The disc crank is made of cast-iron. Centre cranks are *hen the shaft extends* on either side of the crank. They *ally forged in one piece* with the shaft, but weaken it



Centre Crank.

somewhat. Side and disc cranks are secured to the shaft means of keys or shrunk on.

Crank-Pins.

Probably no part of the steam-engine more imperatively requi perfection in material and workmanship than the crank-pin, if co noiseless running is considered desirable. Yet it would be safe say that the cranks of most engines are so imperfectly fitted as to out of line with their shafts. The most frequent causes of troul with crank-pins are lack of parallelism between the pin and sha imperfect material, untrue turning, and inadequate wearing surfa

It is generally understood that, when a pressure exceeding abo 800 lbs. per square inch is imposed upon a journal, lubricati with oil is no longer adequate to prevent destructive wear. the case of crank-pins this limit is frequently approached, and some cases exceeded. Very few engine manufacturers make th crank-pins exceed *one-fourth* the bore of the cylinder in diamet and *one-third* of it in length, the majority being short of this pr portion.

Assuming this proportion, and that the rule for finding t effective wearing surface of a journal is to multiply its diamet by its length, a little calculation will show that the area of t piston exceeds the wearing surface of the pin over $9\frac{4}{10}$ tim Then suppose the piston to be subjected to a pressure of 85 lbs. p square inch, which is not unusual, the pressure on the crank-p will be $85 \times 9{\cdot}4 = 799$ lbs. per square inch. If such a pressu was constant, it is very probable that no material, perfection workmanship, or lubrication would prevent the heating and spee destruction of the pin and boxes; but in the case of the crank-p such pressures are but momentary, and do not last long enou to allow destructive wear to begin. The alternating intervals no pressure assist in the necessary redistribution of the lubrica still, when we multiply the mean pressure on the piston by t *number of times* that its area exceeds that of the pin (ten tim *in many cases*), the wonder will be not that so many pins trouble, but that so many do not. An increase in the dimensions of the pin would, it is true, proportionately diminish the pressure per square inch; but the loss of power, by the increased friction thus induced, would be equally as objectionable as the evil which it was intended to remove.

The length of a crank-pin should be equal to the horse-power of the engine divided by the stroke; the quotient multiplied by a coefficient which has been found by experiment to range from 1·3 to 1·5. For instance: if a crank-pin is required for an engine 24″ × 48″, capable of developing 250 Hp., then $250 \div 48 \times 1{\cdot}5 = 7{\cdot}81$, or $7\frac{13}{16}$ in., which is the required length.

To determine whether a crank-pin is in line with the centre of the cylinder or not, put on the connecting-rod and key the box up snug on the pin; then disconnect the rod from the wrist of the cross-head and move the crank round, and if the rod maintains a central line in whatever position the crank may be placed, the crank-pin is in line with the centre of the cylinder. This test will also serve to prove the correctness of the boring of the pin-boxes. If they are not bored exactly at right angles to the centre line of the rod, troubles similar to those caused by an untrue pin will ensue. Another oversight not generally thought of, and which causes much trouble with crank-pins, is that, in planing off the stub-ends of the connecting-rod, the machinist, through ignorance or inattention, planes more off one side than the other. As a result, every time the rod changes its position, the box will pinch on the crank-pin, and cause undue heating.

The Eccentric.

The Eccentric.—An eccentric is substantially a crank, with its pin enlarged in diameter so as to inclose the shaft on which it is placed within its periphery. It gives exactly the same motion that would be obtained from an ordinary crank of equal throw. The eccentric is sometimes called a cam, which is erroneous, as the latter *is always used to* obtain a motion different from what *can be obtained from a crank.* The term "cam," when use three times their diameter, depending upon the speed. For sh running at 100 revolutions per minute or less the length need be more than 1 to 1½ times the diameter, from 100 to 200 rev tions 1½ to 2 times the diameter, and from 200 to 500 revolut their length should be from 2 to 3 times the diameter. journals are usually bounded on either side by a collar w limits the lateral motion of the shaft. These should be eas rounded off so that no sharp angles occur in the bearings.

The main bearings, pedestals, pillow blocks, or journal b all of which terms have the same signification, usually consi boxes made of brass or some anti-friction metal carried in iron pedestals, which are either bolted to the engine frame or a part of it. In some cases one or more of the bearing entirely independent of the frame of the engine and carried separate concrete or brick foundation. These are called *board bearings* and are used when a flywheel or pulley is p inside the outer bearing, that is, between the bearing and the c

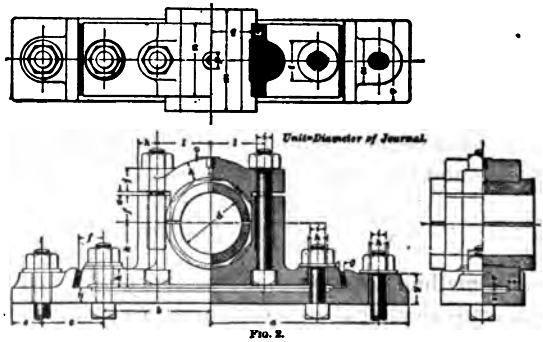


FIG. 2.

Pillow Block.

A very common form of pillow-block is that shown in tl companying cut, which consists of brass bearings carriec cast-iron pedestal. The bottom plate, which is bolted *foundation,* contains oblong holes for adjusting its positio *further adjustment* is had by means of the wedges shown ate and the main casting. The adjustments for taking up ar, etc., require no further explanation. In stationary s the bearings usually form part of the frame, and frequently ie separating the main box and the cap, instead of being ital, is at an angle of about 30° from the perpendicular. done so that the resultant strain passes through the solid instead of through the joint between the box in the cap, it does when this is horizontal.

Fly-Wheels.

object of the fly-wheel is to equalize the motion whenever he power communicated or the resistance to be overcome ble. In the one case, the fly-wheel may be said to be a itor of power. The complicated impulses, acting on the motion, preserve the momenta, without disturbing the ity of movement. The effect of one impulse is so absorbed ibuted in the momentum of the wheel, that it may be said hardly been diminished before the next impulse is re-

other case, or where the fly-wheel is used to overcome a resistance, it may be considered a conservator of power. ver having been exerted in getting up the speed, is retained ioving mass, and the whole of the power expended, with the on of that which has been lost through friction and resist- the air, can be brought to bear at any instant upon the ce to be overcome. When the crank and connecting-rod ne straight line, as they must be twice in each revolution, nk is said to be on its dead-centre, because there the the piston is dead or ineffective. It is evident that, when nk is at right angles to the connecting-rod, the latter is the maximum of power; but when the forward or back- ead-centre is reached, the crank would remain there, but action of the fly-wheel, which, by its accumulated momen- rries it over the dead-centre.

, ***through the momentum*** of the fly-wheel, no perceptible variation occurs in the velocity of the engine; the unequal leverage of the connecting-rod is corrected and a steady and uniform motion produced The fly-wheel, as before stated, is a regulator and reservoir, and not a creator of motion. As regularity of motion is of much greater importance in some cases than in others, the weight and diameter of the fly-wheel must depend on the work and the character of the machinery it is intended to drive; so that, in proportioning a fly-wheel to a given engine, attention must be paid to many particular circumstances rather than to any given rule. There are circumstances under which the use of a fly-wheel may be dispensed with, as where a pair of engines work side by side, whose cranks are at different angles, so that one assists the other to pass the centres, or where smoothness of motion is not an absolute necessity.

Great care should be taken in erecting fly-wheels to see that they are balanced—that is, that the centre of gravity of the wheel coincides with the centre of the shaft, as if it does not both the shaft and the wheel will be subjected to unnecessary strains, which may produce disastrous results. The balancing may be accomplished by loading or cutting away portions of the rim, as the case may require, and it may be said in general that the perfectly circular form of the wheel is of no importance so long as the centre of gravity coincides with the centre of the shaft. The effectiveness of the fly-wheel in steadying the motion of the engine depends upon the distance of the metal from the centre, the weight being the more effective the greater its distance from the centre. For this reason the material of which the fly-wheel is composed should be concentrated as much as possible in the rim. The steadying action also varies as the square of the speed of the rim. Hence, increasing the diameter saves weight. There is a certain limit, however, beyond which the speed may not be increased without danger of bursting. The speed of the rim is rarely above 80 feet per second, and if carried beyond 200 feet per second the strains produced by the centrifugal force would probably be sufficient to rupture the wheel.

ly-wheels are nearly always made of cast iron, and when not y large are cast in a single piece. Very large wheels, howr, are often cast in sections, because of the difficulty of hand- ; as well as the expense of making very large castings. In h cases one section of rim is often cast with one arm and one ion of the hub; more frequently, however, the arms are cast arately, the rim in as many sections as there are arms, and hub in two sections. The sections of the rim are held toher by means of links and cotters, while the arms are doveed into the rim and the hub and secured by wedges. The ves of the hub are bolted together. The arms of fly-wheels uld be made of sufficient size to support the weight of the rim. ey merely act as distance pieces between the hub and the rim, l their weight adds little to the effectiveness of the fly-wheel. e arms are usually given a slight taper, increasing in thickness m the rim to the hub, to provide resistance against the bending ess due to their own centrifugal force.

CHAPTER XVIII.

VALVES AND VALVE GEARS.

The term valve gear embraces all intermediate connections been the eccentric on the driving-shaft and the valves, and is plicable to all mechanical arrangements employed for working valves of steam engines.

The valves most generally employed for the admission of steam the cylinders of steam engines are the slide, poppet, Corliss or nirotary, and rotary; plug- or piston-valves are also used, but erally for steam-pumps. All valves, whether used for the mission or escape of steam to or from the cylinders of steam gines, receive their motion from cams, eccentrics, or cranks. hatever *the device employed to* give motion to the valves may *termed, whether cams,* eccentrics, cranks, gearing, rockers.

wrist plates, toes, lifters, trips, links, rods, levers, etc., they ma be placed under the head of valve-gear.

There are engines without valves, such as the Wardwell, which was on exhibition at the Centennial Exposition at Philadelphia and some kinds of oscillating engines, in which faces on the cylinder fit against faces on stationary steam-chests, through which the steam enters and escapes from the cylinder. Such arrangements are now but rarely used, because they possess inherent defects which render them useless for the most important purposes for which the steam engine is employed.

A "releasing" valve-gear is an arrangement in which the valve is liberated from the control of its moving agent, and allowed t close in obedience to the action of a spring, weight, or other forc independent of that which opened it. The agent which determines the time of release may be the governor, or it may be, and often is, some device adjustable by hand.

An automatic cut-off valve-gear is one in which the movement of the cut-off valve is so controlled by the governor, as to cut off the steam as early or as late in the stroke as may be required, to maintain the desired uniformity of speed, under variations of load and pressure.

A positive cut-off is an arrangement of valve-gear by which the expansion of the steam is effected by what is known as *lap* on the valve, the steam being cut off at the same point in each stroke, independent of load or pressure.

An "adjustable" cut-off is an arrangement of valve-gear, in which the point of cut-off can be adjusted by the hand of the engineer, outside of the steam-chest, by means of a screw, hand-wheel, or other mechanical arrangement, to meet the requirements of work and pressure. The link, in its application to the steam-engine, belongs to this class of cut-offs, as it effects the adjustment of the cut-off by means of coincident variations in the travel and angular advance using a single valve.

Riding cut-off.—A term applied to cut-off valves which ride on the back of the main steam-valve.

dependent cut-off is one in which the expansion is effected
ndependent or auxiliary valve riding on the back of the
alve, and receiving its motion from an independent eccen-

expansion" valve-gear is one that cuts off the supply of
at any required point of the stroke. It embraces all the
ng arrangements.

vhole" stroke valve-gear is one that admits steam through
ole length of the stroke.

eversing" valve-gear is an arrangement employed for re-
the motion of engines. It is effected in different ways: in
ases with a single eccentric, while in others with two ec-
s, as in the case of the link; and in others, still, by means
ose eccentric which revolves on the shaft, but is prevented
aking a complete revolution by two stops so placed that
ests it in the proper position for the forward, and the other
backward motion. This arrangement is peculiarly adapted
oats and ferries, owing to the ease and quickness with which
ine can be reversed.

ble-beat valves are poppet-valves so arranged, that the
e of steam is nearly equal on both sides, thus rendering the
of the valve much easier than in the case of an ordinary
eat valve.

ttle-valves are valves located in the steam pipe, through
steam is admitted to the steam chest. Every engine is
ith a throttle valve, which is turned off when the engine is
hut down.

ef-valves are used on the cylinders of large engines, par-
y marine, to prevent fracture of the cylinder-head and
r, in consequence of an accumulation of water in the latter.
a greater pressure is exerted in the cylinder than would
from the ordinary pressure of the steam, the relief-valve
en and admit of the discharge of the water, thus averting
ident. *They are used on* fire-engines for the purpose of

preventing the hose from bursting when the escape of the wa is obstructed.

Balance-valves.—Arrangements by which the weight on back of slide-valves, induced by the pressure of the steam, is lieved by the action of the steam in the steam-chest.

Rotary-valves.—A term applied to any valve that describ revolution in working.

Semirotary-valves.—A term applied to all valves simila the Corliss that have a vibratory or rocking motion.

Starting-valve gear.—A mechanical arrangement employe connection with a small engine, called the starting-engine, moving the valves of large engines when stopping or starting

Gridiron-valves.—A modification of the slide-valve, contai a number of openings for the steam, by which means its tr and friction are materially diminished.

Dash-pot.—An arrangement employed for closing the va of engines of the Corliss type, and in many instances for arres the closing movement when it is sudden and violent. The d pots contain usually either water or oil, though in many insta they are cushioned with air.

Spring-levers.—Arrangements employed for closing sen tary- and poppet-valves. They are a substitute for the dash- which has many advantages over them, on account of the agreeable noise induced by their workings.

Lifters.—A term applied to the toes on the lifting-rods, wl open and close the valves of steam-engines, particularly t constructed with what is called a Stevens' front.

Wrist-plate.—An arrangement employed in engines of the liss type for transmitting the motion of the eccentric to the val and in many instances for modifying their throw or movemen

Trips.—A term applied to the pawls which liberate the va of engines having what is termed a releasing-valve gear.

Crab-claw.—A term applied to the pawls, which liberate *valve-gear* of engines of the Corliss type from the influenc *eccentric*, when the point of cut-off is reached.

The Slide-Valve.

e function of the common slide-valve is to admit steam to iston at such times when its force can be usefully expended ropelling it, and to release it when its pressure in the der is no longer required. Notwithstanding its extreme licity as a piece of mechanism, no part of the engine is more ing to the average engineer when the problem to be solved determine beforehand the results which will be produced given construction and adjustment, or the proportions and tment required to produce given results. All who have had xperience in constructing and setting slide-valves are aware, general way, that the events of the stroke cannot be independently adjusted; that, for instance, a cut-off earlier than about -fourths of the stroke can only be had at the expense of more s distortion of the other events, and that for some reason, not ys apparent, it is impossible to completely equalize the events e two strokes, occurring during one revolution.

fore explaining the action of the slide valve and the methods vestigating the distribution of steam it will be necessary to ly define some of the terms used in this connection.

mission.—The period during which the steam passages are and steam is admitted behind the piston.

haust.—The period during which the exhaust passages are and the steam is exhausted from the cylinder.

t-off.—The point in the stroke at which the steam port closes.

pansion.—The period during which the steam expands in ylinder, beginning at the point of cut-off and continuing until team is released or the exhaust port is opened.

mpression.—The period during which the steam is comed, which is from the time the exhaust port closes until the f the stroke.

gular advance, the angle which would be formed by the tric when *in its actual position* with the position of the eccen-*orresponding to the central* position of the valve, the crank being on its dead point. In other words, it is the angle by which the eccentric is in advance of the position necessary to bring the valve to its central position, when the crank is on a dead centre.

Travel of the valve, the total distance which the valve moves in one direction. If the valve rod were of infinite length, or if a yoke connection were used, this would be equal to twice the throw of the eccentric. (See page 378.)

Overtravel is the distance travelled by the valve over and above that necessary to fully open the steam port.

Lap on the Valve.—The term lap on the valve denotes the amount the edges of the valve extend over the ports when the valve is in the centre of its travel. The object of lap is to secure the benefit to be derived from working steam expansively. Lap on the steam side is termed outside lap, while lap on the exhaust side is termed inside lap. Poppet or conical valves cannot have any lap, but the same effect is produced as in the case of the slide valve by arranging the cams and lifting toes so that the valve may close at the proper time to give the necessary degree of expansion. The lift of poppet valves, to give an opening equal to the area of the port, is ½ the radius or ¼ the diameter.

Lead is the amount the port is open at the beginning of the stroke. The object of lead is to enable the steam to act as a cushion against the piston before it arrives at the end of the stroke, to cause it to reverse its motion easily, and also to supply steam of full pressure to the piston the instant it has passed dead-centre. It varies in different engines from $\frac{1}{32}$ to $\frac{3}{16}$, without regard to size or kind. Some valves have no lead at all, others less than none, or what is termed "negative lead." The higher the speed and the more irregular the work the more lead will be required for any engine.

Loss of lead is a term employed to express the inequalities of the lead at the two ends of the cylinder induced by the expansion of valve-rod. It may occur, however, at both ends, through lost motion in the joints or displacement of the eccentric.

Lead on the steam end is a term applied to the amount of

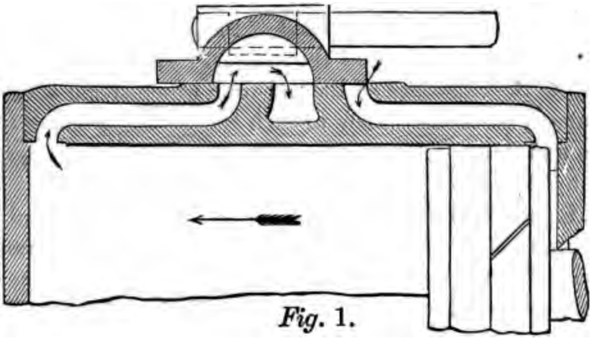


Fig. 1.

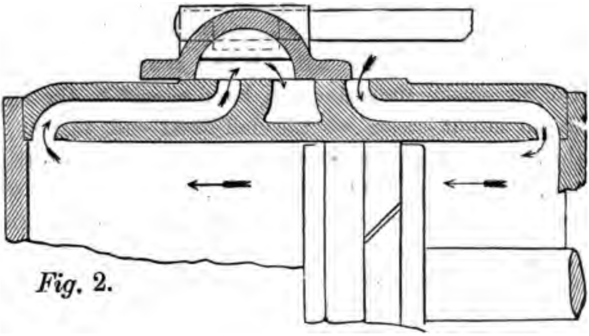


Fig. 2.

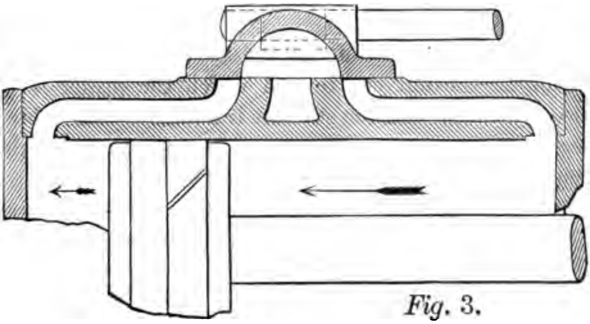


Fig. 3.

he annexed *Cuts show the* Position of the Slide-Valve a
Three different Points in its Travel. (*See explanation on page* 390.)

opening the valve has at the end of the cylinder into which tl steam is entering. Lead on the exhaust end means the amou of opening the valve has on the end from which steam is escapir The name applies alternately to each end of the cylinder.

Line and Line.—A term applied to slide-valves when th have no exhaust lead, as shown in the cut, on page 389.

Fig. I, page 389, represents the position of the piston and valv at the beginning of the stroke, when the latter is just commenci to open. The motion of both, as will be observed, is to the left

Fig. 2 shows the relative position of the piston and val at about ¼ of the stroke; supposing the travel to be equal to t sum of the width of both steam ports and the steam lap at bo ends, so that the ports will be just opened full for the steam, t valve will be moving to the left. When the piston reaches t left end of its stroke the valve will have moved to the right t it begins to admit steam at the left-hand end, just as Fig. shows the admission taking place at the other end, and during tl return stroke the conditions represented by Figs. 2 and 3 will fo low in succession, at nearly corresponding points in the travel (the pistons. If the piston were connected to the crank by mea of a slotted yoke, the events of the two strokes would occur exactly corresponding points in the travel of the piston, but tl connecting rod unavoidably introduces a certain amount of d tortion.

Fig. 3 shows the position of the valve at mid-travel. T compression at the left end toward which the piston is movi has just commenced, and the exhaust is about to take place fro the other end. The events which occur in connection with the sli valve, viz., admission, cut-off, release, and compression, are usual investigated with the aid of the Zeuner diagram, a brief explan tion of which will be given in the following paragraph.*

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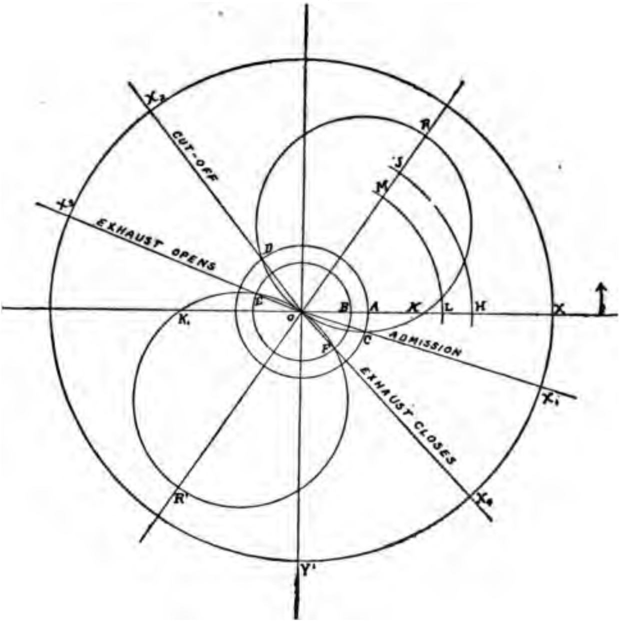
* There are numerous graphical methods employed for investigating t *motions of valves*, but the whole subject is too intricate to be fully explain *this book.* The reader is referred to "Valve Gears," by H. W. Spang *ore thorough* treatment of the subject.

The Zeuner Diagram.

aw a line $O X$ to represent the crank at the beginning of the , and with this as a radius draw the crank circle $X X_1$, X_2, X_3, Suppose the crank to turn in the direction of the arrow. gh the point O draw the line $R R'$, making the angle $R' O Y'$ to the angle of advance, and lay off the distances $O R$ and



Zeuner Diagram.

equal to the eccentricity or throw of the eccentric. On the $O R$ and $O R'$ as diameters draw the two circles $O C R D$ $E R' F$. With O as a centre and a radius $O A$ equal to utside or steam lap draw a circle $A C D$, and similarly a radius $O B$ equal to the inside or exhaust lap, draw a $B E F$. *Through the point* O and the intersections C, D, *F draw the lines* $O X_1$, $O X_2$, $O X_3$, and $O X_4$. We are now able to take from the diagram all of the data necessary for a complete understanding of the distribution of steam in the cylinder:

$O\ X_1$ is the position of the crank when admission of the steam begins.

$O\ X_2$ is the position of the crank when cut-off takes place, hence

$X_1\ O\ X_2$ is the angle traversed by the crank during the period of admission.

$O\ X_3$ is the position of the crank when the exhaust opens.

$O\ X_4$ is the position of the crank when the exhaust closes, hence

$X_3\ O\ X_4$ is the angle traversed by the crank during the period of exhaust, and

$X_4\ O\ X_1$ is the angle traversed by the crank during the period of compression.

The distances from the intersection of the circles R and R' with the lines $O\ X$, $O\ X_1$, etc., representing the crank in its different positions to the centre, represent the travel of the valve corresponding to those positions of the crank. The circle R represents the forward and the circle R' the return stroke, hence

$O\ K$ is the distance the valve has travelled from its central position at the beginning of the stroke.

$O\ K'$, the same for the return stroke.

$O\ A$ is the outside or steam lap, hence

$A\ K$ is the distance the steam port is open at the beginning of the stroke or the steam lead.

$O\ R$ is the full travel of the valve.

$O\ B$ is the inside or exhaust lap, hence

$B\ K$ is the distance the exhaust port is open at the beginning of the stroke or the exhaust lead.

At the points C and D the travel of the valve is just equal to the outside lap; hence in these positions of the crank the steam port opens and closes respectively; similarly at the points E and F the travel is just equal to the exhaust lap; hence, in these *positions of the* crank the exhaust port opens and closes *respectively. If* we lay down from the point A a distance A H, equal he width of the port, and with *O* as a centre and a radius *I*, draw an arc, cutting the line *O R* at *J*.

is the distance the valve travels more than enough to fully open the port, or the over-travel.

imilarly if we lay off from *B* the distance *B L*, equal to the th of the port, and from the centre *O* and a radius equal to draw an arc, cutting the line *O R* at *M*.

R is the distance the valve travels more than enough to fully open the port to the exhaust.

will thus be seen that by a careful study of the diagram all rmation necessary for the proper design and setting of the ve gear may readily be had. For example, in the above diam the cut-off takes place a little later than ¾ stroke. It is lent that if it is desired to have the cut-off take place earlier, at ½ stroke, it will be necessary for the outside lap circle, *D*, to intersect the valve circle *R* in the line *Y Y'*. This be accomplished by increasing the outside lap, by reducing eccentricity, or by changing the angle of advance. However, one of these changes would also affect the entire distribution, it would probably be necessary to lay down several diagrams re the most advantageous dimensions could be obtained.

How to Set the Valves of Steam-Engines.

lo definite instructions that would apply to all cases can be en for setting the valves of steam-engines. As the circumces under which the engines and valves are employed must, certain extent, influence and control this operation, fast-rung engines require more lead than those that run slowly. Enes doing heavy and irregular work also require more lead than e working with a uniform load. Some engines require no lead ll, while others require a great deal.

he valves of a steam-engine may be adjusted with great acacy by an intelligent and practical engineer, providing that *the valve-gear is of correct* proportions; but there are difficulties to be contended with which frustrate the efforts of the most practical mechanics, and must ever do so, unless we discover a new material for valves and valve-gear. Valves may be set with the nicest mechanical accuracy, opening and closing the ports with precision when the valves and valve-gear are cold; but when exposed to high temperatures they may be far from accurate in their travel. All metals expand with heat and contract with cold, and a valve that will give uniform lead at each end of the stroke when cold, will not, in all probability, do so when exposed to the action of the steam, as the valve and valve-rod will expand, produce a loss of lead, increase the amount of lap, and alter the conditions under which the engine was intended to work.

This change is not confined to slide-valve engines, as the stems of poppet-valves are lengthened by expansion, decreasing the lift and also the lead, and inducing a very different condition of things from what would exist if the valves could be used at the temperature at which they were adjusted. Thousands of indicator diagrams show conclusively that the behavior of valves, when exposed to high temperature, is very different from what they are when cold. One of the best aids to correct valve-setting is a good indicator, as nothing shows the action of the steam in the cylinder so correctly as this instrument. It tells exactly when the steam goes in and out of a cylinder, because it maps down the motions of the steam as determined by the motions of the valve and piston, recording faithfully the times and pressures as they actually are.

To set a slide-valve, place the *crank* on the *dead-centre* and the valve centrally on its seat over the ports; then adjust the valve-gear to the right length, and move the *eccentric* round in the direction in which the engine is intended to run, until the proper lead is attained, as shown in Fig. 1, page 389; then turn the engine on the opposite centre, and, if the lead is exactly the same, the valve ought to travel equally on its seat, and the exhaust appear, as in Fig. 2, page 389. Any difference in the lead at *either end must* be equalized by lengthening or shortening the *valve-gear, as* the case may be.

ln intelligent engineer can generally tell by observation whether
ines exhaust regularly or not; as, if the steam is discharged
h long or short puffs, alternately, or shows what is technically
ned a long and short leg, it is evident that the valve has an
lier and a freer exhaust at one end than at the other; never-
less, one exhaust may be heavier than the other, and yet the
ervals between them may be equal. In such cases the exhaust
equal as to time, but not as to amount. The difference in
ount may be caused by unequal degrees of expansion, and this
turn may be caused by unequal cut-off, or unequal clearance,
both. Such inequality cannot be cured by mere adjustment,
ce the lap requires to be changed; but in most cases an im-
vement may be effected by a compromise between equalized
-off and exhaust, so that the effects of the inequality of both
uld not be noticeable.

n the case of fast-running engines, or where the exhaust has
pass through long pipes, this inequality is not easily determined
m the appearance of the exhaust; but it may be done more
urately by holding the ear close to the exhaust pipe. This
ter method may also be resorted to in the case of low-pressure
gines exhausting into a condenser.

w to Determine the Amount of Lap and Lead on a Valve without Opening the Steam-Chest, and whether it is Equal it both Ends or not.

Open the cylinder drain-cocks and disconnect them from the
p-pipes, so that the steam may be seen and heard to issue from
m. A better plan is, to open the holes made for the indicator,
here are any; at all events, open as large holes as possible; then
in a very little steam, turn the engine around by hand, and
e, by the commencement and cessation of the flow of steam,
it where the steam is admitted and cut-off. The point of cut-
can be most accurately ascertained by turning the engine
kwards; the steam will in this case commence blowing at the
e point in the stroke at which it would cease blowing when

turning it forward; and, owing to the elasticity of steam, the commencement of the issue is always more clearly defined than the cessation, particularly when the issuing orifice is small. For the same reason, the point of admission can be most accurately located by turning the engine forward.

To determine the lead, having found the point of admission, make a mark on the valve-stem at a known distance from some fixed point, and another after the pin has reached the centre; this will give the lead. If the admission forward takes place when the crank-pin is exactly on the dead-centre, there is no lead. Having obtained the lead and cut-off for both ends, the travel and length of the connection being known, a diagram may be constructed similar to that on page 391, which will give the lap and port-opening.

The point of exhaust and compression cannot be determined so readily. With a small engine, in which the piston and valve are steam-tight, the points may be ascertained by blowing into the cylinder through pipes attached to the cylinder-cocks or the holes for indicator, if any. The exhaust would be indicated by the point where the air would begin to pass through into the exhaust, and the closure, by noting the point where it ceased to pass through.

But in engines of any size, especially leaky ones, the plan of blowing in with the mouth would be inapplicable. With non-condensing engines, however, much may be learned by listening to the exhaust; if the puffs occur at equal intervals, and are of equal force, good equalization may be inferred; and, if they are short, quick, and free, and are followed by a free and nearly noiseless escape of the residuary steam, the exhaust is early and ample enough. On the other hand, too late an exhaust will produce more prolonged and labored puffs. It is needless, however, to remind the reader that nothing can take the place of the indicator for determining all the conditions and adjustments of the valve, particularly its exhaust and compression, as, even when the nicest measurements and calculations are resorted to, doubts may still exist as to the truthful movements of the valve, which nothing but an application of the indicator can satisfactorily remove.

TABLE

G THE AMOUNT OF "LAP" REQUIRED FOR SLIDE-VALVES WHEN THE STEAM IS TO BE WORKED EXPANSIVELY.

n the travel of the valve is known, and the point of cut-ided, the following table will show the amount of lap re-*

l e e	The Travel of the Piston when the Steam is cut off.							
	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{10}{12}$
s.	The required "Lap."							
	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$
	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$
	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{3}{4}$
	$1\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	1	$\frac{13}{16}$
	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$
	$2\frac{1}{8}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1
	$2\frac{5}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$
	$2\frac{1}{2}$	$2\frac{7}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$
	$2\frac{3}{4}$	$2\frac{9}{16}$	$2\frac{7}{16}$	$2\frac{3}{32}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$
	3	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{3}{8}$	$2\frac{3}{32}$	2	$1\frac{3}{4}$	$1\frac{7}{8}$
	$3\frac{3}{16}$	3	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{32}$	$1\frac{7}{8}$	$1\frac{1}{2}$
	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{3}{8}$	2	$1\frac{5}{8}$
	$3\frac{5}{8}$	$3\frac{5}{16}$	$3\frac{3}{16}$	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$
	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{5}{16}$	3	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{7}{8}$
	4	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{3}{16}$	3	$2\frac{13}{16}$	$2\frac{3}{8}$	2
	$4\frac{1}{4}$	4	$3\frac{13}{16}$	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{1}{2}$	$2\frac{1}{16}$
	$4\frac{7}{16}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	$3\frac{5}{16}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{3}{16}$
	$4\frac{9}{16}$	$4\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{1}{2}$	$3\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{1}{4}$
	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{5}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$
	5	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{1}{8}$	4	$3\frac{5}{8}$	3	$2\frac{1}{2}$

e for finding the point of cut-off required to produce a given al from a given initial pressure.

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a valve has ¾ lap, it will overlap each steam-port ¾ of an inch when *ntrally over them.*

Divide the total terminal by the total initial pressure. The quotient will be the point of cut-off in decimal parts of the stroke.

Example.—Initial pressure, 20 lbs. per sq. in. Terminal, 13 lbs., measured from a vacuum. Then 13 lbs. ÷ 20 = ·65 of the stroke; or divide the volume of the initial by that of the terminal, the quotient will be the point of cut-off in decimal parts of the stroke.

Example.—Vol.* of 20 = 1220. Vol. of 13 = 1846. Then 1220 ÷ 1846 = .663. of the stroke.

Rule for finding the point of cut-off when the initial and mean pressure are known.

Add the pressure of the atmosphere to the initial and mean pressures, and divide the mean pressure by the initial. Then find in the table of multipliers, page 328, the number nearest the quotient. Find the number opposite to it in the expansion column, and divide 100 by it; the quotient will be the point of cut-off in decimal parts of the stroke.

Example.—Stroke of piston, 10 ft. Initial pressure, 10 lbs. per sq. in. Mean pressure, 8 lbs. Mean effective pressure, atmosphere added, 22·50. Initial pressure, atmosphere added, 24·5. Quotient of first divided by last, ·918. Expansion number in table opposite, ·919, which is nearest number to above quotient, 1·6; 100 ÷ 1·6 = ·625 or $\frac{5}{8}$ of the stroke. Either of the foregoing rules will make the cut-off take place a trifle earlier than it would in practice.

Different Forms of Slide Valves.

A certain amount of power is always consumed in driving the valve, because the pressure acting on the back of it causes frictional resistances, which in some cases are very considerable. It has been assumed by some authorities that as much as one-fourth of the power of an engine is wasted, while others claim that the loss of power is merely nominal. An idea has been very generally entertained by engineers that the number of square inches in a slide-valve, and the pressure of steam in pounds per square inch, *represented* the total pressure on its back; or, in other words, that essure was equal to the total pressure of steam on the back alve, minus the upward pressure on an area equal to that steam ports. This method of calculating the pressure on lve seat is not, however, entirely correct, because the num- square inches in a slide-valve, and the pounds pressure per e inch, represent only the weight on its back if we consider lve as a solid block of iron, with a smooth surface resting on oth, solid bearing, perfectly steam-tight, in which case the would press on every square inch of surface with the same as a dead weight. There is good reason to believe that such tions are never found in a slide-valve, except in one position, when the valve overlaps both ports and the engine is at rest. on, however, as the valve moves, the steam enters the open port, he pressure is partially taken off that end of it. There is no , however, that in many cases the power required to operate alve is very great, and the better the slide valve fits the seat ore power it will take to work it. A valve that fits its seat ately—that is, in such a way that there can be no leakage of between its face and the seat—requires much more power ive it than one which is leaky, because the pressure of the is all on the seat and there is nothing to lessen the friction t the lubrication.

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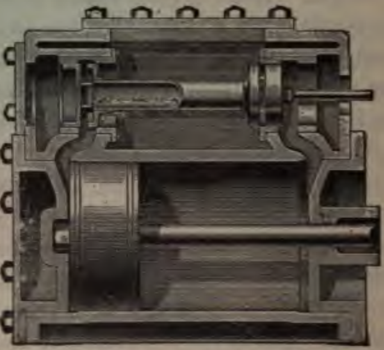
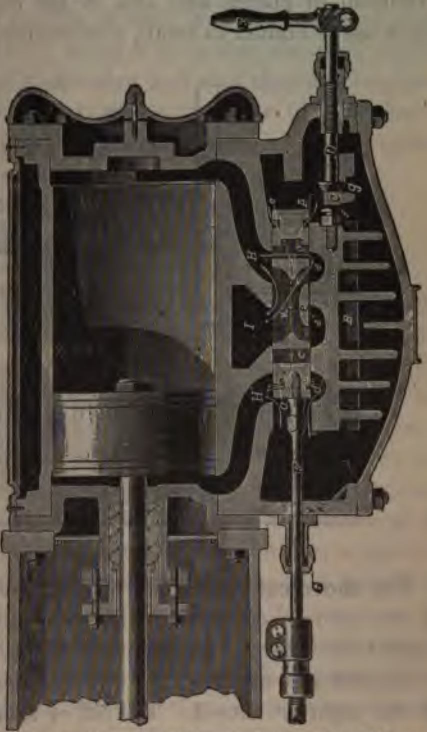
* See Table of Volumes, page 149.

e piston valve has been designed to meet this difficulty. This of slide valve is illustrated in the accompanying cut, which sents the cylinder and valve of the Armington & Sims en- It will be observed that in this piston valve the steam, d of producing pressure on the seat, is evenly balanced, onsequently the only pressure against the seat is that due to eight of the valve; for this reason these valves are known s *balanced valves.* As usually constructed, the valve chest is d, the bushing being accurately turned to form the valve and the valve is made tight by the use of piston rings, the as steam pistons. In the Armington & Sims type it will be that the steam *enters the cylinder* around the inside edge of *lve, and also through additional* passages cut in the valve itself. In this way the effective opening of the port for a given travel is greatly increased. The exhaust takes place around the outside of the valve, so that in reality the inside is the steam lap and the outside the exhaust lap, instead of the outside being the steam and the inside the exhaust lap, as in ordinary D-slide valves. The principal objection to piston valves is that the seat is liable to wear unevenly—that is, at the bottom only, and thus to become leaky. If care is taken, however, to watch the steam distribution by means of the indicator, this is not a serious matter, because, as usually constructed, the seat may be readily removed and a new one slipped in place with very little expense. The piston type of valve is used on many of the best types of stationary high-speed engines, because it is light, simple, and perfectly balanced. It is also much used in marine engines, especially for the high-pressure cylinder.


Piston Valve. Armington & Sims' Type.

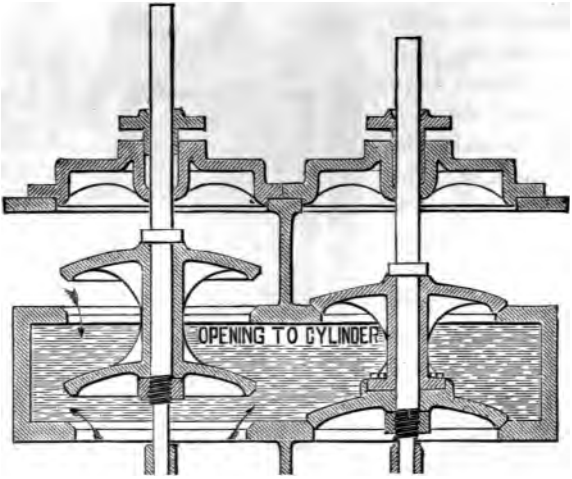
The excessive pressure of the flat valve against its seat and the evils resulting therefrom have also been obviated by making the valve in such a way that the pressure of the steam is not exerted against the back of the valve. An effective method of accomplishing this is illustrated in the next cut, which represents *the cylinder* and valve of the Woodbury Engine. It will be observed *that* in this type, which may also be called a balanced eam pressure does not act on the back of the valve between its seat and the relief plate *B*. The relief le in two parts, forming a wedge, and the whole is so at by means of the lever *E* on the outside of the the relief plate may be forced against the back of r separated from it by any desired amount. By this te adjustments may be quickly made and the valve ight without offering undue frictional resistance. The adjustment y a suitable is set on f the steam t the plate orced down r than is make the tight. The lever *E* is valve to be om its seats hould stick engine has g idle. The steam into around the lso through ry ports *a* ch are con- passages at bottom. In the crank cylinder is m, and, as en by the



Balanced Flat Slide Valve. Woodbury Type.

ıters around the end of the valve at H′, through the passage d'' and through the openings *A* and *a* at the ot end of the valve, so that virtually steam is admitted at f points in the valve at the same time. Consequently the stean not throttled to any extent when it enters the cylinder. I similar manner the exhaust is doubled by means of the passa $c c'$, as is clearly shown in the cut.

Poppet valves are those which open by rising from their se instead of sliding. They are extensively used for the water (tribution in pumps and also in gas engines. In steam engi their use is limited to small, slow-running marine engines.



The above cut represents poppet,* or double-beat, valves, s as are used in connection with the Stevens' Cut-Off, or what termed the Stevens' Front. It will be observed that the val on the left side are open for the admission of steam, while th on the right are closed. The lift of such valves, if single, wo be about ¼ of their diameter; but when they are double, as

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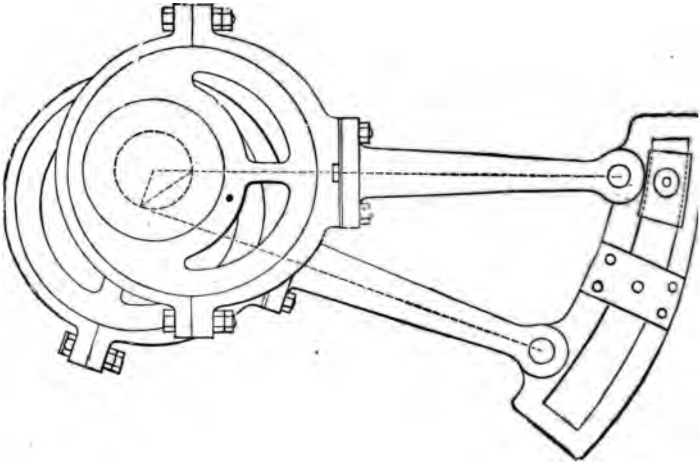
* *Puppet* is the correct word, though poppet is most generally adopted *engineers.*

: present case, $\frac{1}{8}$ lift would give an area equal to the opening of : steam-port. One of the greatest difficulties experienced in the rking of such valves is, that, however carefully they may be ;ed, their stems will expand and induce leakage in the valves ıen exposed to a high temperature. For this latter difficulty ere appears to be no remedy.

Nevertheless such valves have their advantages, among which e, that they can be turned up, or ground on to their seats at a oderate cost, since the process of their manufacture is all lathe ork; that in their working, there is no power absorbed by fricon, as in the case of the slide-valve, and that they can be placed near the cylinder as to reduce the clearance to a minimum. ıch valves, however, would not answer for high-speed engines, cause they would not seat.

Variable Cut-off and Reversing Gears.

In order to reverse the direction of motion of an engine opeted by a slide valve and single eccentric it is evident that the centric would have to be slipped around on the shaft until it cupied the same position relative to the valve on the opposite de of the shaft, while in order to vary the rate of expansion or ıt-off it will be evident from an examination of the Zeuner diaam on page 391, that some means must be found for effecting a ıitable variation, either in the steam lap or in the travel of the ılve. Both of these methods are used; the former, a variation the steam lap, is employed in Myer's gear, which will be deribed below, while the latter, a variation in the travel of the ılve, is the principle employed in nearly all automatic cut-offs ith fly-wheel governors. These will be described under "Govnors" in the next chapter. Finally, there is a device, invented Stephenson, by means of which the engine may be not only versed, but the cut-off varied to any desired extent in a very mple manner. *This is called the link motion.*



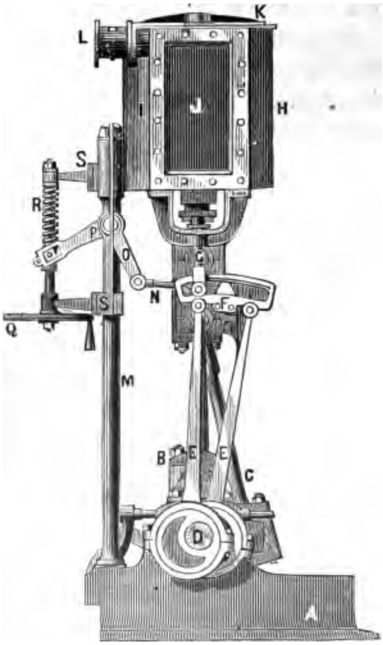
The Link.

The link-motion is an arrangement of valve-gear for reversin engines and varying the rate of expansion. It consists of tw eccentrics, with straps and rods. The eccentrics are so place that when one is in the right position for the engine to move fo ward, the other is in the position for moving backward; and b raising or lowering the link, motion will be communicated to th valve and the engine will move backward or forward. The r sult of this combination is that the link receives a reciprocatin motion in its centre; since, when one eccentric is moving the en of the link in one direction, the other is moving the other end i the other direction; so that the link will have nearly the sam motion communicated to it as if it were suspended from a piv at its centre.

The horizontal motion communicated to the link by the joi action of the eccentrics, is a minimum at the centre of its lengt where it is equal to twice the linear advance, and it increases t ward the extremities, being nearly equal at either extremity t *the motion* which would be imparted to it by the eccentric at th *extremity alone*, without regard to the other. The valve rod *l to* a block which slides in the link, and the positio this block is varied by means of a combination of rods and levers, attached in some cases to the block and in others to the link tself. In either case the link is suspended by a rod at some point, and the length of this rod as well as the location of the point on the link to which it is attached, have an important influence on the motion of the link.

The travel of the valve depends upon the distance of the block from the centre of the link. By moving the link up or down on the block or the block up or down in the link, the travel of the valve may be increased or decreased. The central position corresponds to no motion whatever, while the nearer the block is to either eccentric the more its motion will be under the control of that eccentric. Now since the travel of the valve, other things being equal, determines the point of cut off, it follows that the degree of expansion varies with the position of the block relative to the link. In the above sketch, for example, suppose that the front eccentric is set for forward motion and the back eccentric for reverse motion. The link is suspended at the centre by a rod (not shown), and in the position represented in the cut the block s at the top, and it is therefore entirely under the control of the forward eccentric. Consequently the engine is going forward and the steam is cut off at the latest possible moment, the exact point of the stroke where the cut-off takes place depending on the lap and other dimensions of the valve gear. Now as the link. is raised the travel of the valve decreases and the cut-off takes place earlier until the block is in the centre, when there is not enough travel to uncover the ports; hence steam may be said to be cut off before the stroke begins and the engine is at rest. If the link is raised still more, the other eccentric will control the block and the engine is reversed, the cut-off depending, as before, on the distance of the block from the centre of the link. The *term* "full-gear forward" means that the link is dropped to its full extent; while "full-gear backward" means that the link is lifted to its full extent. *When the link-block stands directly under the saddle-plate both ports are closed,* and neither admission nor exhaust can take place. The distance between the block and the end of the link when in full gear is termed the clearance.

The radius of the link is the distance from the centre of the driving-axle, or shaft on which the eccentric is located, to the centre of the link; while the link itself is a segment of the circle of that diameter. The length may be greater or less, but any variation from these proportions will give more lead at one end than at the other while working steam expansively; but the radius may be several inches shorter or longer without materially affecting the motion. The vital point in designing a valve link motion is the point of suspension of the link. If it is suspended from the centre, it will invariably cut off steam sooner in the front stroke than in the back stroke, while working expansively. It is customary to suspend the link at the point which is most used in running the engine. In the accompanying cut the method of attaching the link to a vertical engine is shown.

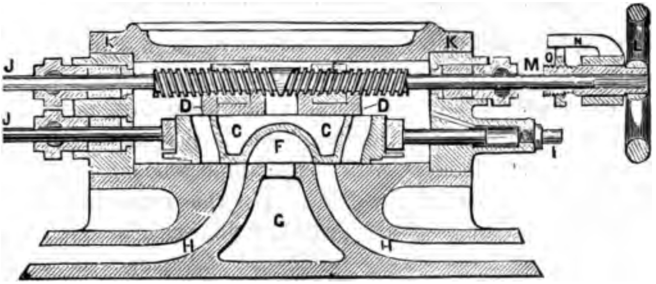


A A shows the bed-plate; *B*, the pillow-block bearing; *D*, the shaft; *E E*, the eccentric rods; *C*, the connecting-rod; *F*, the link; *G*, the cross-head wrist; *J*, the bonnet of steam-chest; *I H*, the steam cylinder; *K*, the cylinder-head; *L*, the steam-pipe; *M*, the front column which supports the cylinder; *N*, the reach-rod; *O*, the reverse arm of the bell-crank by which the link is moved back and forth; P, the lifting arm; *R*, the by means of which the link is reversed; S S, the guides ugh which the spindle of the screw *R* moves; *Q*, the hand-el by which the lifting arm *P* is moved up or down for the pose of changing the position of the link. In the type of link l for locomotives the screw and hand-wheel is replaced by a ; lever moving in a notched segment, the notches correspond-to the various cut-offs on the forward and reverse motion.

he ease and facility with which the link may be handled are y important features in its favor. In fact, what could we do out it when handling engines, especially large locomotives or ine engines, which have of necessity to run backward with same ease, speed, and facility as they run ahead? The link splendid mechanical conception, and one of the greatest im-vements that has ever been made in the locomotive, marine ine, or any other class of engine requiring a reversing gear.

Meyer's Valve Gear.

very simple and effective method of varying the rate of ansion without interfering in any way with the admission, ase, and compression, is by means of what is known as a *ng cut-off*, which consists of an additional valve to control the off, riding on the back of the main or distribution valve. re are numerous varieties of this type of valve, but perhaps most widely used is the Meyer valve. This is illustrated in accompanying cut, in which *C C* is the main or distribution e. This is similar to an ordinary *D* valve, except that the



steam, instead of being admitted around the ends of the valv enters the cylinder through ports as shown. The main or distr bution valve admits steam and opens and closes the exhaust i exactly the same way as a plain slide valve. The cut-off, how ever, is effected by means of a separate valve, *D D*, called th riding cut-off or expansion valve. As will be seen, it consists o two blocks containing nuts, which are carried on a right- and lef hand screwed spindle *M*. By turning the wheel *L* on the outsid of the steam chest the distance between the blocks may be ad justed, and in this way the cut-off or degree of expansion varie to suit the conditions. The main and expansion valves are op rated by separate eccentrics, and if the engine is to be reversib the main valve may be actuated by a link motion. The wheel may be operated either by hand, or it may be connected with centrifugal governor in such a way that the cut-off will be regi lated automatically. The principal objection to this type of valv is the excessive loss in friction of the valves against their seats.

Separate Valves for Admission and Exhaust.

The valves and valve gears which have been described abov are all open to the great objection that the steam enters th cylinder through the same ports which have just been coole off by the exhaust. The result of this is that, especially whe the passages are long, a very considerable amount of energy lost by condensation in the ports. For this reason, and also i order to effect a more advantageous distribution of steam, separa valves are now frequently used for the steam and the exhaus Engines of this kind are known as *Four Valve Engines*, and the increased economy in the use of steam amply justifies the addi tional complication introduced by the separate valves. *Corli Engines*, with their semi-rotary valves, belong to this class. Th valve gears of this class of engines will be described in Chapter XI

CHAPTER XIX.

STEAM-ENGINE GOVERNORS.

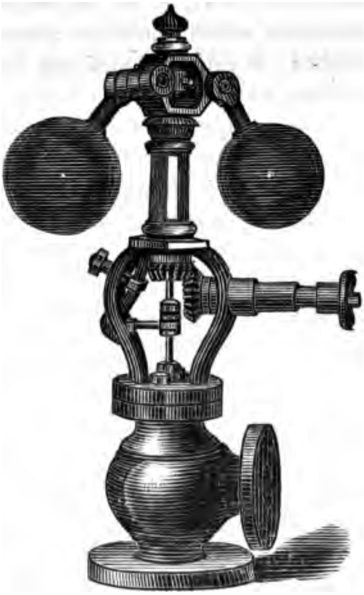
e subject of regulating the speed of steam engines has of ears received no little attention from engineers and practical ors, and as a result various kinds of governors have been uced. It would be safe to say that this device has absorbed thought, and re- more attention part of mechan- an any other ad- of the steam-en- In the first gov- the principal f the apparatus ted of a pair of revolving round cal axis or spin- iven by a train chanism, gener- itre-gears, which their angular ve- of revolution to fixed ratio to the ty of the prime . The rods of endulums place elves at an an- ith the vertical o that the common height of the pendulums is that corre- ng to the number of turns in a second. The regulator must

The Waters Governor.

be so adjusted as to be in the proper position for supp proper amount of power when the pendulum-rods are at of inclination corresponding to the proper speed of the When the speed deviates above or below that amount, ward or inward motion of the pendulum-rods acts on th so as to open the valve when the speed is too low, and when it is too high.

In the attainment of this object, the principle of ce force, as embodied in the old fly-ball governor of Watt, more resorted to than any other; but, aside from this, the has been so improved, altered, and reconstructed, since as to be almost unrecognizable; but still the old pri there, and also the three prominent defects which so m interfere with its efficiency. The first of these is frictic arises from the joints, and is caused by swinging the weights by the short end of the arm or lever to which attached. The second defect is due to the fact that the they assume different positions in keeping with the sp which they revolve, are obliged to rise or fall. This is in order that the resistance which the weights offer to ce force should constantly increase; if it did not so incr weights, when once started from their position of rest, stantly go to the extreme limit of motion. The rising of shortens the distance which they are allowed to move fo variation by bringing the centres of ball and arm on wl swing into a straight line, so that a variation which m balls a given distance upward, if it occurs again, will r them nearly so far in the same direction. Again, the sa that would support the balls in any plane would not ra to that plane from a lower one. So between friction, w stroys the delicate power that the balls assume under change, and the necessity for a large change to overco inertia, it is almost impossible to attain a degree of re which would be equal to all requirements.

Governors when attached to throttle-valves work tances that necessitate the use of openings for the passage of team that are too small in area, so much so that the useful ts of the steam are considerably diminished. On this depends ll repute of throttling engines as compared with those which late by governor controlled valve motions or variable cut-off. e valve of a governor has too large openings, it will, owing e unsteady action of the governor, admit too large a quantity eam, and cause a jumping of the engine; then, in trying to off this extra amount, it shuts it all off; in fact, the governor ot fix it exactly right, being incapable of delicate changes. difficulty is best met by making the openings in the valve culiar shape, so that they open and close in a ratio different that of the governor. With a governor that would run per- y up to theory, and be steady and capable of taking a posi- in keeping with the speed, not leaving it without a ge in speed, a very large might be used, and the l effects of the steam would be impaired, neither would exist a necessity for great ges in speed to get the re- d opening and closing of valve. The extra amount eam required to drive a y addition of load on an e is surprisingly small, ided that the engine can get team at the very instant the is applied, and before the entum of the machinery mes much reduced; but he engine once get below l, the *circumstances will ry different, as, even with-*



The Shive Governor.

out any load, the engine would take some time to come t speed.

The third defect in governors on throttling engines is that th spindle or valve-stem has of necessity to pass through steam-tigh packing- or stuffing-boxes, which have to be screwed up to pr vent leakage, without any guide save the judgment of the e gineer, which increases the friction and interferes with the fr action of the governor. There is also the friction on the governo valve necessary to overcome the power required to move th valve-stem through all its bearings, stuffing-boxes, guides, etc under the pressure of steam. Were it possible to construct governor for throttling engines which would approach in practic what theory would demonstrate, the fly-ball or centrifugal gov ernor would be a perfect regulator; but this appears, according t mechanical laws, to be impossible. By the use of isochrono governors, which would not admit of any variation of speed, b would be in equilibrium at any speed, whether the balls were u or down, or in any other position, the defects of the common gov ernor were supposed to be obviated; but it was found by exp rience that power and stability were necessary, and isochronis in its strict sense unattainable.

In the fly-wheel governor these defects have been partiall eliminated. True, there is still a certain amount of friction i the joints, but this can be made insignificant by proper lubrica tion. On the other hand, there are no packing or stuffing boxe to stick, as in the case of the throttling governor, and, above al the full pressure of the steam acts upon the piston at the begi ning of each stroke, independent of the load on the engine, an consequently there is no energy lost in expanding the steam befor it enters the cylinder. The action of the throttle valve in reduc ing the pressure of the steam is simply an expansion without any useful return, and consequently a waste of energy equivalent to the heat which was necessary to raise the steam from the pressur

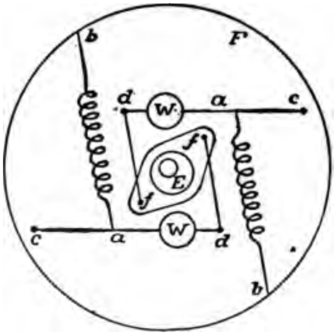
h it is used to the boiler pressure. For example, the en-
tained in one pound of dry steam at 100 pounds pressur

uivalent to about 912,670 foot-pounds, while at 80 pounds ure it is about 908,450 foot-pounds. Hence, if a boiler furs steam at 100 pounds, and this is reduced to 80 pounds by ction of the governor on the throttle, it may be said that lifference, or 4220 foot-pounds of energy, is wasted by the rnor, because the steam expands without doing any useful . Let us see what would be the result of this in a throtengine of 100 horse-power: An engine of this kind would re about fifty pounds of steam per horse-power every hour, ience the total steam consumption would be 50 × 100=5000 ds per hour. Now for each pound of steam consumed by ngine there would be a waste of energy of 4220 foot-pounds, total waste of 4220 × 5000 = 21,100,000 foot-pounds per or 21,100,000 ÷ 1,980,000 = 10.7 horse-power. In other s, if the engine is running under such a load that, in order intain a constant speed it is necessary for the governor to e the pressure from 100 to 80 pounds per square inch, there e a loss of energy amounting to over 10 (theoretical) horser. Of course, it must be remembered that this energy could ave all been converted into useful work on account of the other losses which are incurred in the passage of the steam gh the engine, but the example serves to show that the of energy caused by the use of throttling governors are a important factor, especially in large units. This defect is ly eliminated in the fly-wheel governor, and in all types of nors where the regulation is produced through the cut-off, not by means of the throttle valve. Moreover, it has been l that much closer regulation is attainable with the aid of nors of the latter class, and also that there is less variation piston speed during each single stroke. (See also "Throtand Automatic Cut-off Engines," page 346.)

r these reasons nearly all modern steam engines, excepting ughest types, are equipped with governors which act upon ut-off. There are several methods in common use by which *ction is produced, the most* common being the fly-wheel gov-

ernor, the action of which will presently be described, the C
governor and valve-gear, and the governor which prod
changes in the cut-off by varying the position of the block
link, such as is used in the Porter-Allen engine. Each of
types will be illustrated in the next chapter, which will b
voted to a description of the most important features of so
the best-known types of steam engines.

The action of the fly-wheel governor, which is the type
on most high-speed engines—that is, engines of high speed of
tion, may be briefly explained as follows: Referring to
diagram, F is the rim o
fly-wheel. The arms c d
the weights W, and are pi
at c to the fly-wheel arms
shown). The springs a b
attached at a to the arms
and at b to the rim of th
wheel. The links d f e
from the ends of the arms
either end of a collar f f, w
is placed loosely on the
shaft, and which carries th
centric E. Now when th
wheel revolves there is a tendency for the weights W to t
outward—that is, away from the shaft, and the force (centri
force) which actuates them to move in that direction is cou
acted by the tension of the springs a b. If the speed incr
this tension is partially overcome and the balls move out
and in so doing shift the eccentric E, changing its eccentr
angle of advance, or both, and thus producing an earlier c
in the cylinder. It will be readily understood how the te
of the springs and the weights, W, may be adjusted so as to
tain a position of equilibrium and thus produce an approxim
uniform speed of rotation. As a matter of fact, the results w
n attained in this direction are highly satisfactory



Fly-wheel Governor.

th the aid of a well-designed governor of this type, it is pos- le to regulate the engine to within one per cent. of its rated ed when the full load is thrown on or off.

The economy of a good governor has rarely been appreciated owners of steam-engines and steam-users.* Experience has wn the speed best adapted for each and every process in the nufacturing and mechanical arts, and the governor that fails meet all the varied requirements of each process is of no value an economical point of view. Every stroke which an engine kes below its regular speed increases the cost of production, d every stroke above it is a waste of steam, and consequently fuel. If an engine is geared to run at 80 revolutions per nute, when a heavy piece of machinery is thrown off, the vernor admits of an increase of speed of from 10 to 15 revolu- ns per minute. This incurs a waste of power, and consequently vaste of from 12 to 20 per cent. of fuel. On the other hand, en a heavy piece of machinery is thrown on, the governor ows the engine to lag behind its regular speed by from 10 to 15 okes per minute; this increases the cost of production. If a gov- nor is unreliable, it is worthless; if reliable, its first cost is merely nominal consideration. There are many processes, such as mill- , weaving delicate fabrics, printing from small type, or the y accurate turning of fine material, where a good governor is immense value.

Governors are sometimes attached to marine engines for the rpose of equalizing the revolutions in heavy sea-ways, and pre- nting the engines from racing, which is caused by an insufficient mersion of the paddle-wheels or propellers, and which may be ribed either to the lightness of the load or the heavy swell the sea. But from whatever cause racing may occur, it is vays attended with danger, as the undue strain to which the chinery is subjected is liable to result in a breakdown.

Governors should be kept perfectly clean and free from accu- lations induced by the use of inferior oil, as such gummy sub- nces *have a tendency* to interfere with the easy movement of the different parts. Many first-class regulators have been condemned as not being capable of controlling the engine at a uniform speed, when all that was required was a good cleaning.

Governor-spindles working through stuffing-boxes should be frequently and carefully packed, as, when the packing becomes old and dry, if screwed up to prevent leakage, it interferes with the free action of the governor.

Rules for calculating the size of pulleys for governors.—*To find the diameter of the governor shaft-pulley.* Multiply the number of the revolutions of the engine by the diameter of the engine shaft-pulley, and divide the product by the number of revolutions of the governor.

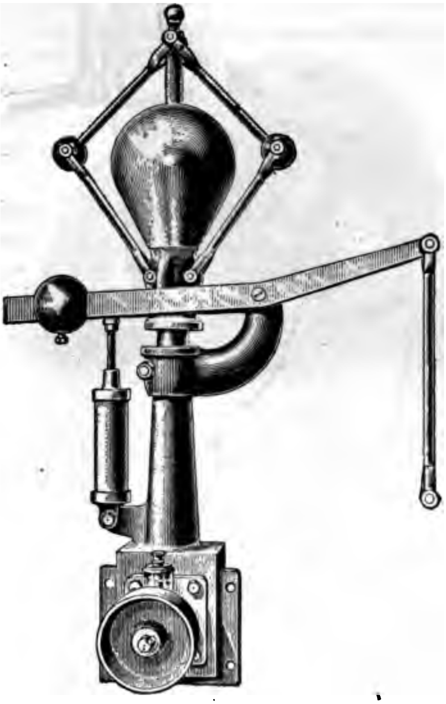
To find the diameter of the engine shaft-pulley.—Multiply the number of revolutions of the governor by the diameter of the governor shaft-pulley, and divide the product by the number of revolutions of the engine.

Description of Different Governors.

Throttling governors are those in which the centrifugal force of a pair of weights acts upon the throttle valve of the engine. There are hundreds of types in use, but they differ only in the details of construction, the principle in all being the same as that employed by James Watt in the early days of the steam engine. Waters' Governor, illustrated on page 409, is a fair representative of this type. In this the springs shown are used to aid the force of gravity in resisting the centrifugal force of the balls—in other respects this type requires no further explanation.

Porter-Allen Governor.—In this type of governor the regulation of the speed is effected by altering the position of the block in a slotted link attached to the eccentric. Both the governor proper and the eccentric with its link are illustrated in the accompanying cuts. The former, as will be observed, is a loaded pendulum governor, and, though it was first designed in connection with the Porter-Allen engine, it is now frequently used in ction with Corliss gears, and also as a throttling governor

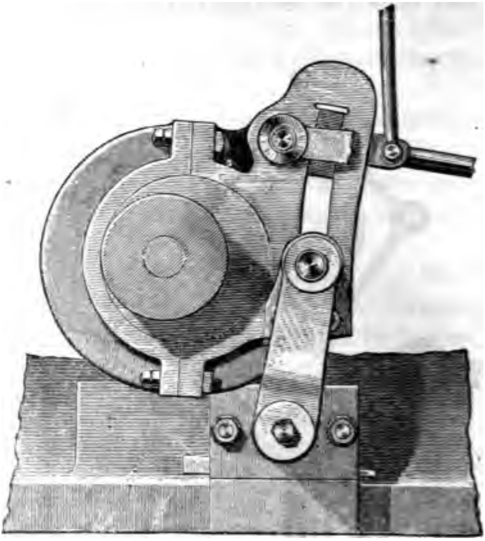
-valve engines. One of its chief advantages is that the
ess is more nearly constant with varying speeds than
ary forms of pendulum or even fly-wheel governors.
al link shown on the right of the first cut moves up and



Porter-Allen Governor.

the speed varies, and as this is attached to the link shown in the second cut, the travel of the valve and cut-off are varied with the load on the engine. The link
in *one piece with the* eccentric strap, and is pivoted as
he operation of this governor is very simple, and the

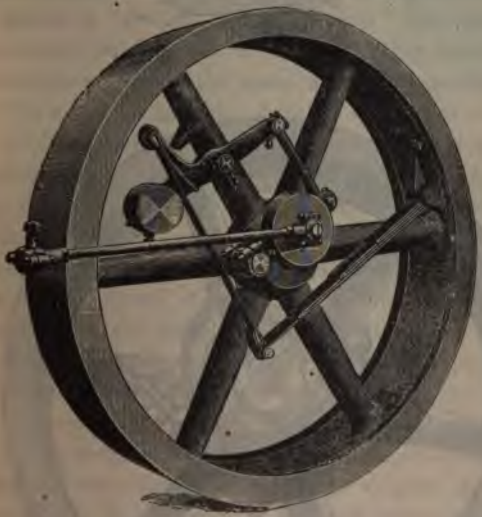
regulation which may be attained very close, so that it is adapted for electric lighting or any other kind of service requires constant speed.



Porter-Allen Link.

Corliss Governor.—In the Corliss type of engines the [illegible] is usually of the pendulum type; but instead of [illegible] valves of the engine, it actuates what is [illegible] which in turn determines the point [illegible] there are four separate valves, two [illegible] two for the exhaust. The latter [illegible] and hence the opening and [illegible] Neither does the governor [illegible] is also constant. In the [illegible] design of the engine plays a [illegible] description of the [illegible] mechanism [illegible] the next chapter.

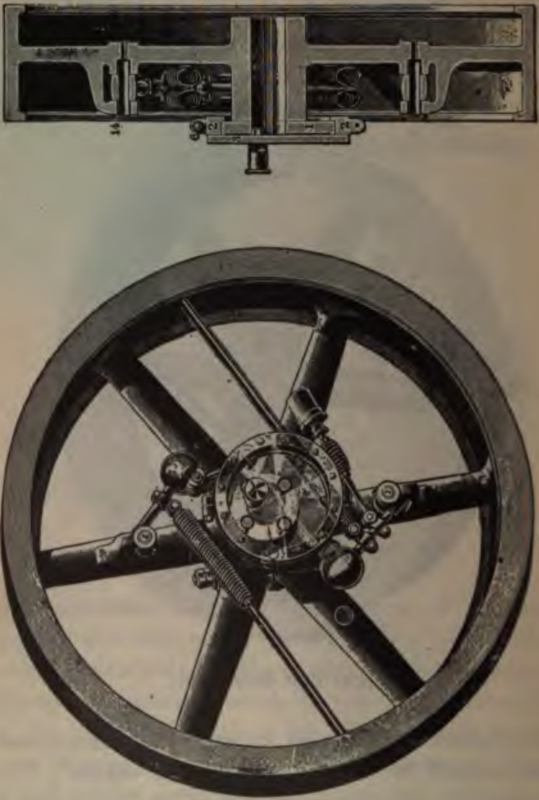
Straight-line engine governor, illustrated in the accom- g cut, consists of a single weight carried on one end of an arm is pivoted in the middle to one of the arms of the fly-wheel. l strap connects one side of the arm to the end of a flat steel , while the other side of the arm is linked to the eccentric h a manner that when the weight travels away from the which it does as the speed increases, the eccentric is shifted



Straight-line Governor.

g both the eccentricity and the angle of advance, and thus tes the cut-off to suit the load on the engine. The gov- is adjusted by altering the weight of the ball, which is cast and weighted with lead shot. This is one of the simplest of der types of fly-wheel governors and it has proved a very sful one.

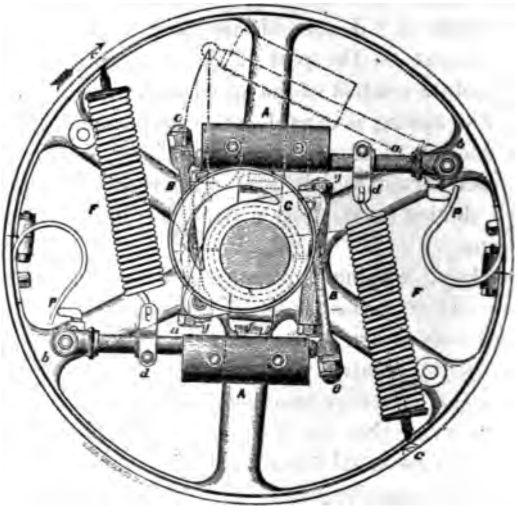
Ball-engine governor *is* similar to the straight-line governor *respect, that both the* angle of advance and the eccentricity are varied in order to produce changes in the cut-off. In the tails of its construction it differs in many ways. Referring to cut, it will be observed that there are two weights, two sets



Ball Governor.

spiral springs, and in addition a dash pot attached to one of *weight arms.* The eccentric sheave, 1, is bolted to the hub of *fly-wheel,* while the strap is made in two parts, 2 and 3, the ing a disc which carries a crank-pin, 4, to which the valve-rod attached. The weights are connected by links to the eccentric raps, so that when the weights overcome the tension of the rings and move away from the shaft, the strap and disc are tated around the sheave, giving the pin, 4, a motion in the arc a circle whose centre is the centre of the eccentric sheave, and this way the desired variations of the eccentricity and angle of lvance are obtained. The supplemental spring and dash pot are ed to provide a "double elastic cushion" for checking any due movement on the part of the regulating mechanism and suring absolute control of the speed under the greatest variation load. The spring is capable of either tension or compression, that a motion of the weights in either direction immediately ts it under strain, which is at once relieved by the dash pot. ence the device exerts only a steadying influence on the speed the engine.

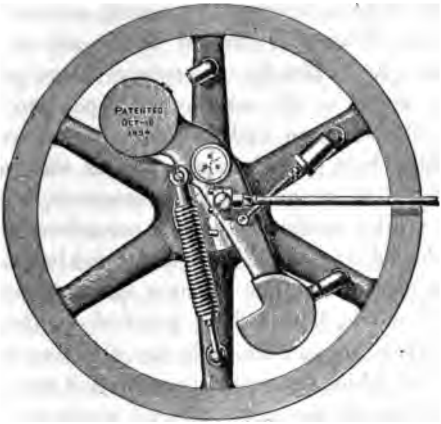
The Buckeye Engine Governor, illustrated in the next cut, is e of the oldest forms of shaft governors. In the Buckeye ngine two valves are used, a main or distribution valve actu- ed by a fixed eccentric and a cut-off, or an expansion valve tuated by the governor mechanism. By referring to the cut, will be observed that the governor differs from those hitherto scribed in this essential feature: that the angle of advance only varied by the centrifugal action of the weights, this being all at is necessary. In the case of a single valve operated by a aft governor, if the angle of advance only is altered, the cut- may be varied to suit the conditions of load, but in that case e lead will also vary in such a way that it would increase as e cut-off decreased. If, on the other hand, the regulation is rformed by varying the eccentricity alone, the reverse would ke place, and hence for shaft regulation in connection with a gle valve it becomes necessary to vary the eccentricity and angle advance simultaneously. This is not the case where a separate stribution and expansion valve are used as in the Buckeye gine, because the admission and exhaust closure are effected by the distribution valve, and the governor acts only on the off. Referring now to the above cut, it will be seen that governor consists of two weighted arms, *a a*, pivoted at one e the wheel and connected at the other to the ears of a loose ec tric, *C*, by means of links, *B B*. The tendency of the ar move outward by virtue of their centrifugal force is resiste the action of the spiral springs *F F*. As the speed increase



Buckeye Engine Governor.

centrifugal force of the weights partially overcomes the pull o springs, and the eccentric is shifted or advanced and thus the [illegible] to take place earlier. This governor was invente [illegible] and it is still in use in essentially the same form as origi constructed.

Rites' Inertia Governor.—This is a recent device of simple construction for regulating the speed by means of the off. Referring to the cut, it will be seen to consist of a weig arm suspended upon a stud to one of the arms of the fly of the arm and its weights being counteracted by a g. The valve-rod is attached to a pin on the arm as h pin moves in the arc of a circle, of which the stud e. Stops are provided on two of the arms to prevent motion of the arm, and the movements of the latter steadied by the action of the dash pot shown. The he pin being in the arc of a circle both the eccentricity of advance are varied. This governor, though of



Rites' Inertia Governor.

ention, has become very popular on account of its mplicity, and is now used on many of the high-speed otably by Armington and Sims, who for many years own designs of governors. Formerly, when a new type r was invented, it was customary to design a whole new sell it on the merits of the governor, but to-day there an enough types of high-speed engines to supply the d new governors, such as the Rites and the Sheppard, some of the older engines under license.

CHAPTER XX.

DESCRIPTIONS OF STEAM ENGINES.

Corliss Engines.

To this class belong all engines, whether simple or co condensing or non-condensing, horizontal or vertical, i the distribution of steam is effected by the aid of the known Corliss gear. Briefly, this type of valve-gear co four separate valves of the semi-rotary type, two for a and cutting off the steam and two for the exhaust, th being controlled by a special mechanism in such a way ports are opened to steam by a fixed eccentric, but at point in the stroke, determined by a pendulum govern valves are released by the eccentric and quickly closed b of springs or dash pots. The exhaust valves, usually c by the same eccentric, have a fixed point of opening and The engine is therefore an automatic cut-off engine, but on of the method by which the cut-off is controlled certain ad in the distribution of steam are effected which make it in many respects to most other engines of the automati type. There being separate ports for admission and exh fresh steam entering the cylinder does not come in cont surfaces which have been previously cooled by the exh furthermore, the valves being very close to the piston, t are extremely short, and hence the condensation in th passages is reduced to a minimum. The valves themse formed of portions of cylinders oscillating on valve face responding form, and they are so arranged that the pressu steam forces them against their seats only when the ports a —when open they have practically no friction to o Hence the power used to operate the valves, which is

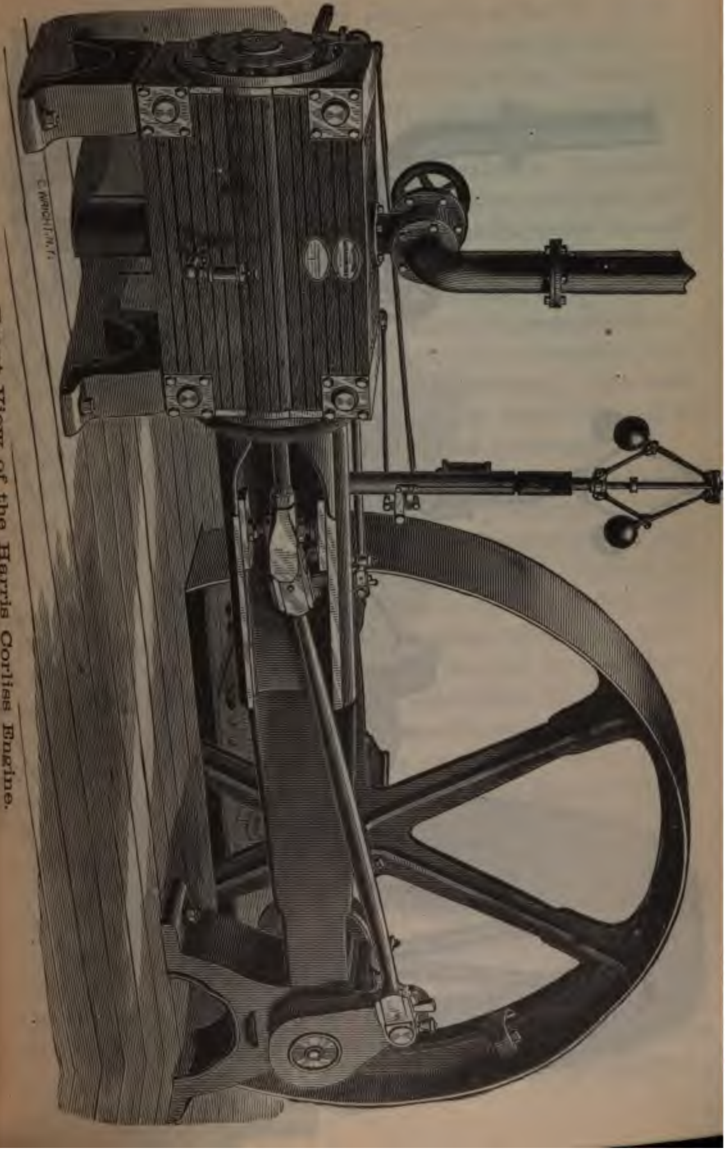
in the case of slide valves, is practically *nil* in the Corlis
while at the same time a tight joint between the valve and
is insured. The effect of the springs or dash pots is to se
very quick closure of the ports, and hence the indicator di
shows a perfectly clean, sharp cut-off, instead of a rounded o
in the case of plain slide valves. Finally, the admission, ope
and closing of the exhaust being independent of the governo
Corliss type of valve-gear has the advantage over automatic
offs with shaft regulation, that the lead and compression ren
constant under all conditions of load, the entire regulation be
had by varying the point of cut-off.

There are innumerable different styles of Corliss Engin
nany of which are excellent, and the economy in the use of stea
nd the close regulation which has been attained certainly mal
his class of engines very desirable for a great many purpose
wing to the method of effecting the cut-off, they are, howeve
nited as to speed of rotation, and it is consequently customar
secure the advantages which are to be derived from high-pis-
n speeds by making the stroke very long. Of course, this
nders them unfit for direct coupling to electrical and other
achinery which needs to be run at a comparatively great num-
r of revolutions per minute, but there are many other uses to
ich the Corliss engine can be put with advantage. It would lead
too far if we were to attempt to describe all of the different
s of Corliss Engines which have proved successful, and besides
uld involve a great deal of repetition. Among the best
n types the following are worthy of especial mention:
olds-Corliss, built by the Edward P. Allis Co. of Milwaukee,
the Hamilton-Corliss, built by The Hooven, Owens & Rent-
Co. of Hamilton, O., the Wetherill-Corliss, built by Robt.
rill & Co. of Chester, Pa., the Atlas-Corliss, built by the
Engine Works of Indianapolis, Ind., and the Harris-Corliss,
y the Wm. A. Harris Steam Engine Co. of Providence,
The last will be more fully described as a representati
lass of engines.

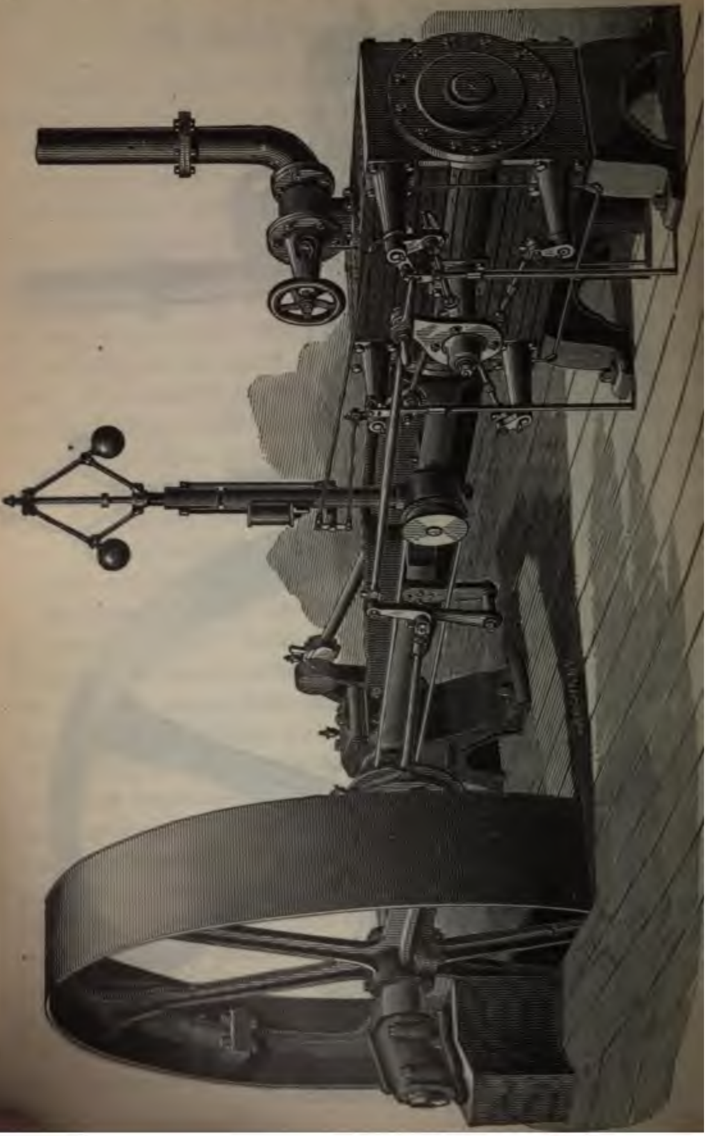
The Harris Corliss Steam-Engine.

The cuts on pages 427 and 428 represent the Harris Corliss Engine, one showing the crank and cross-head, the other the eccentric and valve gear. It will be observed that the general design is symmetrical and well proportioned, rigidity and strength being introduced principally where the greatest longitudinal strain occurs, viz., between the cylinder-flange and the centre of the fly-wheel shaft. Between these points the frame, which is in one casting, is vertically deep and strongly ribbed, thus insuring greater strength and stiffness than could be obtained by any other distribution of the same amount of material. The cross-head guides are cast with the frame. The main pillow-block is of an improved design, with the feet well spread out; and the cylinder and exhaust-chest rest upon supports the entire width of the chest. The engines are only slightly elevated above the floor, thus allowing the attendant to reach every part with the greatest ease. The cylinders and chests are neatly lagged in black walnut, or other wood.

The piston-packing is of the most improved kind, and is claimed to remain perfectly steam-tight under all circumstances. It is set out by means of German silver spiral springs, which obviate the difficulty arising from the cylinder becoming worn larger at the ends, or its liability to become cut or fluted, in consequence of its being set out too tight. Besides, the piston-rod is retained exactly in the centre of the cylinder. The spring plates for the packing-rings are made of bronze metal, consequently they are not liable to corrode. The distance used for the packing-ring between the piston and the follower is so small that it leaves a large amount of the junk-ring for a bearing, or a wearing surface on the lower side of the cylinder in the horizontal engine, which reduces the liability to cut. The design and arrangement of this packing afford the most convenient facilities for taking it out, putting it in, or for adjustment. The operation of the packing is as follows: When steam is admitted into either end of the cylinder, the



Front View of the Harris Corliss Engine.



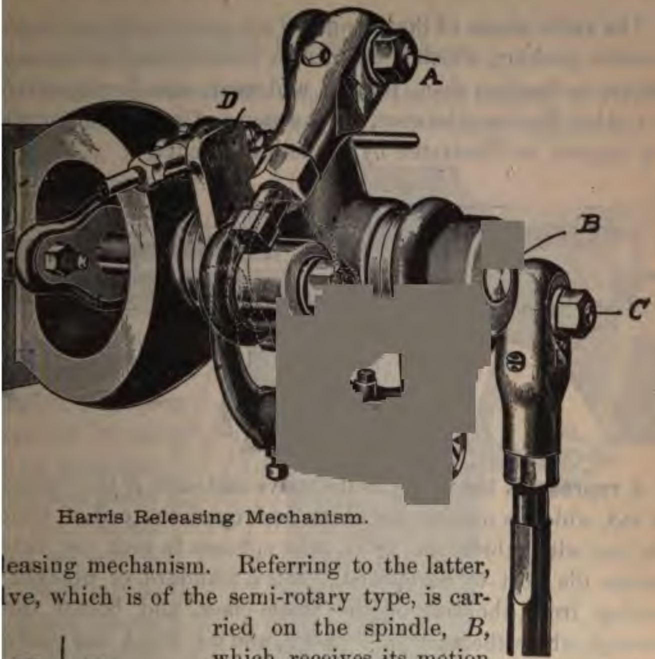
king-ring is carried by the steam over to the side of the groove he junk-ring, making a joint there, and allowing the steam to down and under the packing-ring, thus placing it in equilium; then all that is required is a very light spring to hold the king in contact with the cylinder.

here are four valves—two steam and two exhaust. The steamres are located on the top of the cylinder at each end, and directly into the clearance, which obviates the waste induced the use of long passages. The exhaust-valves are placed in exhaust-chest on the lower side of the cylinder, and, as in the of the steam-valves, open into the clearance spaces, which argement facilitates the escape of the water of condensation from cylinder, and obviates the liability to accident. The four res are moved by one eccentric through the intervention of a t-plate; the same valves admit and cut off the steam.

he steam-valve in these engines commences to open its port at end of the cylinder when the eccentric is producing its most d movement, and, as the motion of the eccentric is declining ards the end of the throw, an increasing speed is obtained by ns of the wrist-plate, which compensates for the slow motion he eccentric. At the same time the steam-valve at the oppoend of the cylinder commences to lap its port by the motion he eccentric, but by a reverse or subtraction of speed proed by the same wrist-plate, which speed is constantly decreastill the throw of the eccentric is completed. Or in other ds, the lapping and opening of the steam-ports require each the e amount of throw of the eccentric, producing, for instance, a of ½ an inch at one end of the cylinder, while the opposite has an opening of one inch and one-eighth. The exhaustres are moved by the same eccentric and the same wrist-plate re spoken of, but they have a much greater travel for the pose of ridding the engine of the exhaust steam easily through exhaust-ports, which are as long and twice as wide as the m-ports, and therefore back pressure on the piston of the enis avoided. The rapid opening and slow lapping of the ex haust-ports are obtained in the same manner as in the case of the steam-ports, but much faster, as the travel is greater on the opening of the exhaust than on the opening of the steam-port, in order to get a free and full opening.

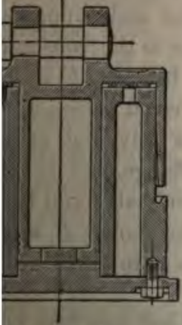
The variations of load upon these engines are communicated to the steam-valves instantly by the governor, the valves being moved by a force distinct from it, yet subjected to its regulation. The governor in no case performs any work, and only indicates the changes required to the levers which move the valves, and needs only sufficient force to move a small stop. Its movement is attended with the least possible friction; the stop presents hardly any resistance to the governor, except at the very instant when it is in actual contact with the lever constituting its fulcrum. This momentary resistance by the bearing of the lever on the stop as a fulcrum occupies so small a space of time that, compared with the period during which the governor is left free to move the stop, it is practically nothing. As a precautionary measure, a safety stop is connected with the valve-gear, so that in case the governor should become inoperative, and should fail to act, the steam-valves become unhooked, and cannot open, and, as a universal result, the engine is stopped, although the valve in the steam-pipe may be wide open. The valves are circular, and oscillate on fixed bearings in the front and back bonnets. The valve-stems have flat blades, which extend the whole length of the valves in the steam-chest, and to which levers are keyed for the purpose of giving them motion. The valves are fitted in such a manner as to be capable of adjusting themselves to their seats, as their faces and seats become warm. Any one of them can be adjusted independent of the other, and can be removed from the valve-chests by unscrewing four bolts, and withdrawing a key at the point at which it is attached to the lever. The valve-gear of these engines may be worked by hand, even under extreme steam pressure.

The automatic **cut-off feature** will be understood from an examination of the accompanying cut, which shows an enlarged view of



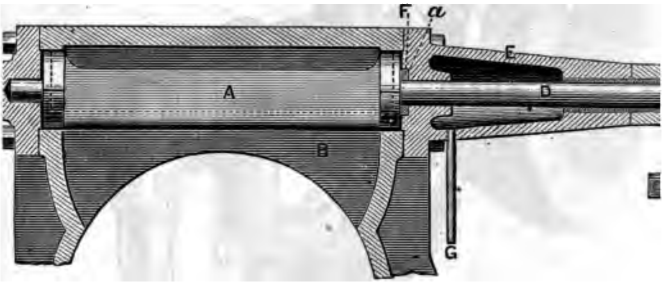
Harris Releasing Mechanism.

leasing mechanism. Referring to the latter, lve, which is of the semi-rotary type, is carried on the spindle, *B*, which receives its motion from the wrist-plate by means of a rod which is attached at the point *A*. The motion of the governor is transmitted to the releasing mechanism by means of the rods shown at *D*, and this motion is used to effect the release of the valve from the wrist-plate. As soon as it is released the dash pot, which is attached to the bottom of the rod *C*, quickly pulls down and thus closes the valve. It will be observed that there are no springs used in chanism, the closing being effected entirely by means of the ot, which *is very simple* and will be understood from the anying sectional cut.



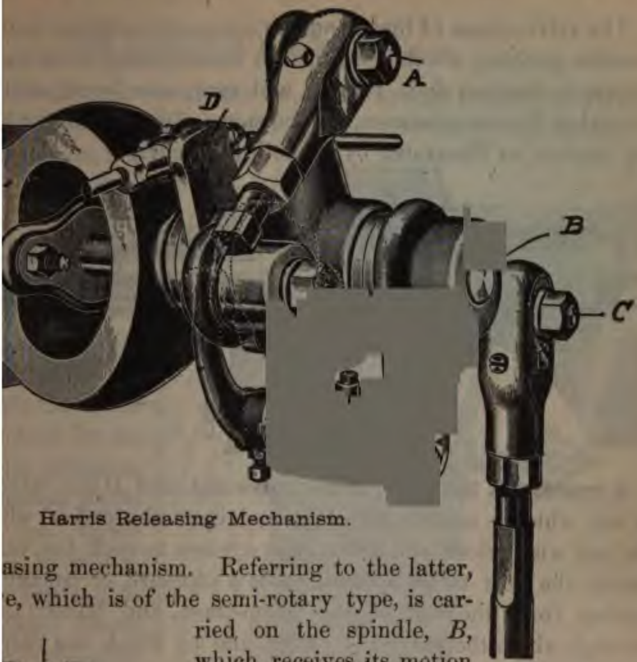
Dash pot.

The valve-stems of these engines are packed with an imj metallic packing, which is claimed to possess many advant respect to freedom from friction and wear, over hemp, cot any other fibrous substance, for the stems of oscillating or ing engines, as illustrated by the following cut:



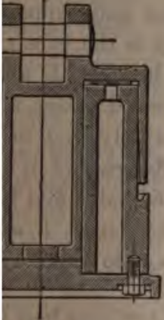
A **represents the valve,** *B* the valve-seat, and *D* the valv or rod, which is outside the chest, and upon the end of wh the toe with which the valve-gear engages to rock the va enable the port to be opened. *E* is a standard or bracke jecting from the side of the steam-chest, and bolted tl through which the valve-rod passes, and by which the val and the valve connected with it, are sustained and suppor their proper relation, all of which is familiar to the constr of steam-engines. At the inner end of the bracket, *E*, an entric with the hole through which the valve-rod passes, a s cut. A collar, *F*, is then shrunk upon the valve-rod, or wise tightly fitted thereto, so as to make a flange, and is t off to face and fit the recess when the valve-rod, valve, and b are in their proper relation. The face of the flange, *F*, ar seat of the recess, *a*, should also be round, so as to make a tight joint.

The Harris-Corliss Engine is one of the oldest and best k types of Corliss Engines, and besides the distinctive features *original Corliss* engine, it contains many improvements i *details of* construction. It is built by the William A. I Engine Co. of Providence, R. I.



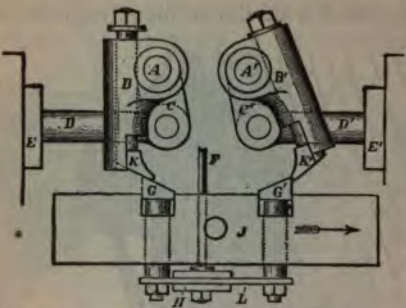
Harris Releasing Mechanism.

asing mechanism. Referring to the latter, e, which is of the semi-rotary type, is carried on the spindle, *B*, which receives its motion from the wrist-plate by means of a rod which is attached at the point *A*. The motion of the governor is transmitted to the releasing mechanism by means of the rods shown at *D*, and this motion is used to effect the release of the valve from the wrist-plate. As soon as it is released the dash pot, which is attached to the bottom of the rod *C*, quickly pulls down and thus closes the valve. It will be observed that there are no springs used in anism, the closing being effected entirely by means of the , *which is very simple* and will be understood from the *ying sectional cut.*



ash pot.

The governor, which is of the Porter loaded pendulum type connected to this gauge plate that, as the speed increases, the is lowered, and vice In the diagram E E resents the steam and D D' the valve- to which are attach arms C C' of the levers A A'. B B sockets which enab toes K K' to rise. operation of the valv may now be explai follows: As the slidi J moves, say, in the tion of the arrow, the back of the tappet G' engages the and opens the valve attached to the stem D' to steam. Evi this will take place at exactly the same point in each stro dependent of the position of the governor balls; hence the constant. As the motion continues the toe will be relea some point in the stroke, depending on the height of the G', or, in other words, on the position of the governor When it is released the toe drops into its original positic closes the valve quickly. In the meantime the other toe been forced into the socket B, as shown in the cut, from position it drops by virtue of its own weight when the ta has moved far enough to the right. On the reverse str course, the other toe is brought into action, and the valve opposite side of the cylinder is opened and closed in a manner. The amount of opening of the steam valves a point at which they are closed are determined by the height tappets, which, as has already been stated, are under con the governor. The governor has a safety-stop motion, so ar that should the governor belt run off or the governor stop ing, the admission of steam to the cylinder would be pr



Valve-gear of Improved Greene Engine.

other respects the engine offers no special features. It has
n in use for many years, and has proved very successful under
ditions similar to those which render the Corliss type of en-
es desirable. It is built by the Providence Steam Engine
npany, of Providence, R. I.

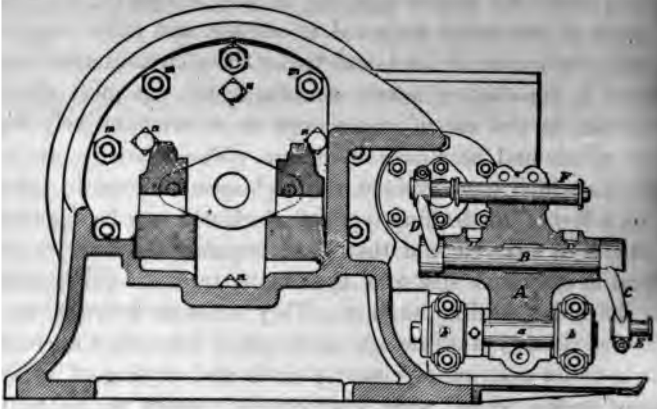
The High-speed Automatic Cut-off Engine.

The class of engines known as the high-speed automatic cut-
type, which now comprises a large variety of designs, owes its
elopment largely to the unusual growth of electric lighting
n isolated plants, and electric railway service. Engines of this
s, while applicable under various conditions, are designed
marily to meet the requirements which the nature of this ser-
e imposes. An engine used for driving a lighting or power
lerator is constantly subjected to sudden, and often very con-
erable, variations of load, and under these circumstances must
intain a constant or nearly constant speed. It must also be
nomical in the use of steam, run at a comparatively high
ary speed, and be simple in design. These, briefly, are the
ditions which have evolved the high-speed automatic cut-off
gine, a few of the leading types of which will now be described.
general, it may be said that these engines, while not so eco-
nical in the use of steam as the Corliss type, are vastly better
n the old throttling engines. They consume from thirty to
ty-five pounds of steam per horse-power hour when operating
ler a boiler pressure of eighty pounds, and cutting off at one-
rter stroke, while, when compounded, which is frequently
e, their steam consumption is about twenty-five pounds. The
lation of the speed, which can be effected to a great nicety, the
iation being often less than two per cent. from the normal
n the full load is suddenly thrown on or off, is usually by
ns of a single valve and shaft governor, although this arrange-
t is modified in some instances, as in the "Four Valve,"
ickeye," *and "Porter-Allen"* engines.

'hile there are a great many different designs of engines of the automatic cut-off, high-speed type in existence at the presen day, the whole class may be illustrated by a description of a fe representative engines, the difference in most being mainly in details of construction. Among those of American manufactur which have proved successful, the following may be mentioned Straight Line, Porter-Allen, Buckeye, Armington & Sims, Ideal New York Safety, MacIntosh & Seymour, Ball, Ball & Wood Atlas, Ames, Watertown, Fisher, Payne, Russell, Woodbury, Cooper, Imperial, Alfree, and others.

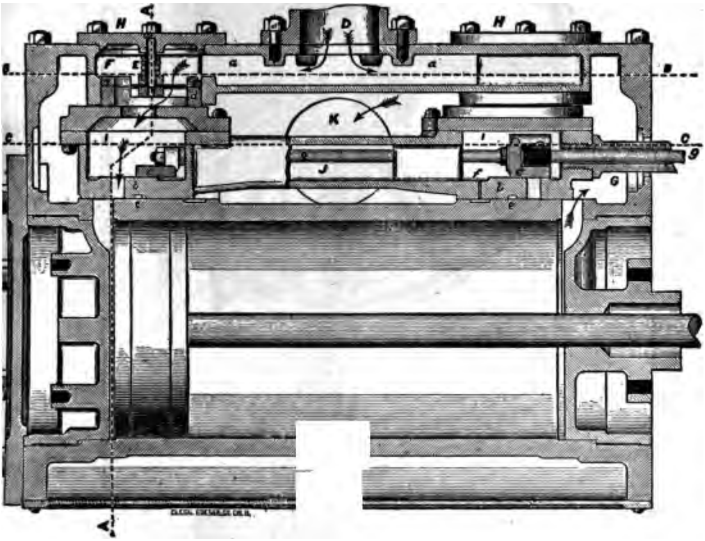
The Buckeye Engine.

Several different designs of engines built by the Buckeye Engine Company, of Salem, Ohio, are known as Buckeye Engines. These differ mainly as to the style of the frame, which is in every case designed to meet the particular requirements of the engine. That illustrated on pages 438 and 439 represents the "Girder Frame" type, because its cross-section resembles that an I girder. It is provided with feet under the cylinder main bearings, and sometimes with an additional pedestal pl *midway* between the two.



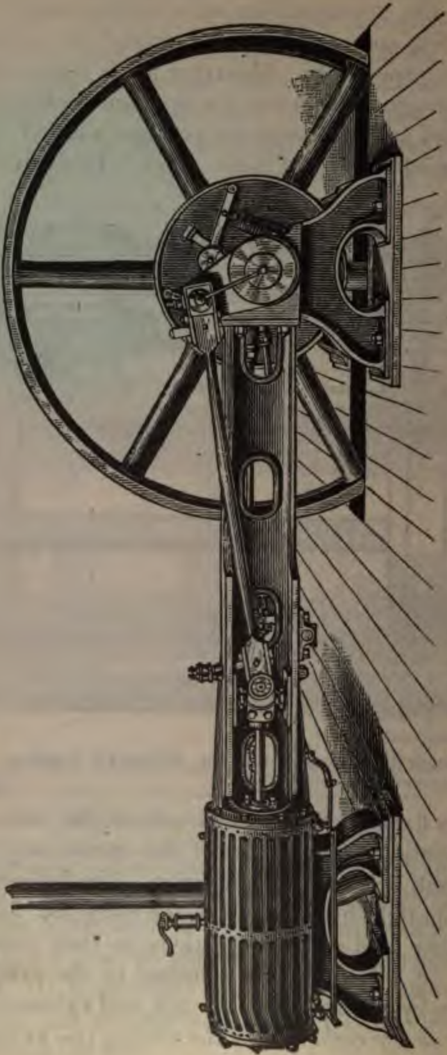
Section through Bed and Rock.

The valve gear of this engine, which is its main peculiarity, is ustrated in the accompanying cuts, which represent sections rough the bed and rock-arm and through the centre of the am cylinder respectively. Referring to the latter, which at the ft shows the course of the steam, the live steam enters the chest at e point *D* and passes through the passages *a a* and balance pisns *d* into the interior *I I* of main valve. This valve derives its

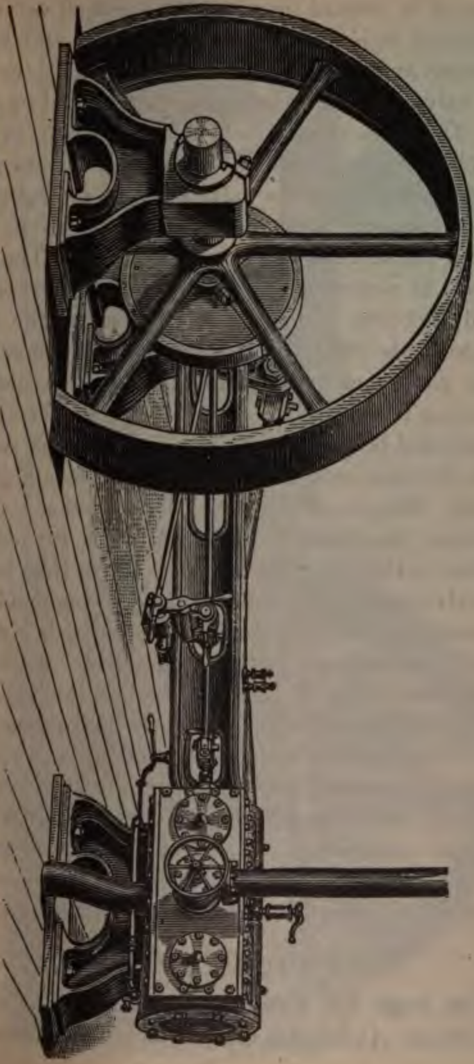


Section through Cylinder, Buckeye Engine.

otion from a fixed eccentric, which acts on the rock-arm shown the other section. The nature of this motion and that of the ut-off valve will be explained presently. The balance pistons *d* re made steam-tight by means of piston rings and followers, the prings *E* being used for holding them to their seats when the team is shut off. The steam is admitted to the cylinder in the anner shown by the arrows on the left, and exhausted as shown y *the arrows on the right* and in the centre, the exhaust passing



Front View of the Buckeye Automatic High-Pressure Out-Off Engine.



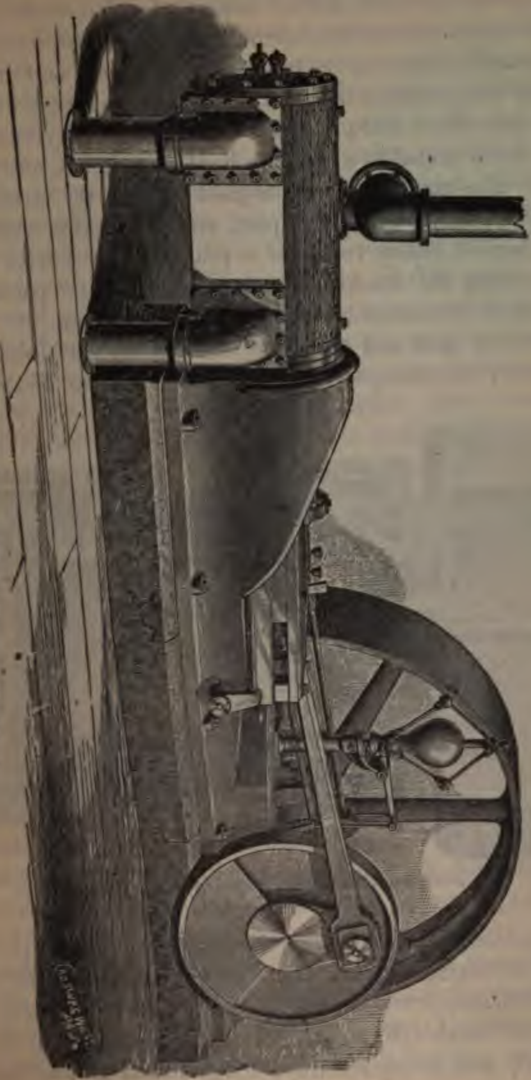
Back View of the Buckeye Automatic High-Pressure Cut-Off Engine.

through the space *G*, outside of the valve, and leaving by the pipe *K*. The cut-off is effected by means of a cut-off valve operated by the combined actión of the main eccentric and the cut-off eccentric, whose angular advance is determined by the governor. The cut-off valve consists of two plates, *c c*, placed on a common valve-rod. The main valve is held against its seat by the steam pressure, and this is relieved by the balance pistons and relief chambers or recesses cut in the valve seat, the arrangement being so proportioned that the average pressure on the valve is just sufficient to keep the surfaces in a good condition. The motion of the valves will be understood by referring to the section through the bed and rock-arm. In this cut, *a* represents the rock-shaft, which vibrates in the adjustable bearing *b b*, attached to the engine frame. The main rock-arm *A* is attached to this shaft and receives its motion from the fixed main eccentric referred to above, the main valve-rod being attached at *F*. The cut-off rock-shaft *B* is carried in the main rock-arm, and has arms *C* and *D* attached at either end. The cut-off eccentric, whose motion is determined by the governor, takes hold at the pin *E*, while the cut-off valve-rod is attached to the end of the arm *D*. It will thus be seen that the cut-off valve derives its motion from the combined action of the two eccentrics. Its travel on the main valve is constant, and hence there is no tendency to "wear shoulders" on its seat. In many of the newer forms of Buckeye Engines the flat valves are replaced by piston valves for use with very high pressures.

The type of engines shown on pp. 438 and 439 are simple, slow-(rotary) speed horizontal, non-condensing engines, but they can be and are built on the same general lines to run at high speeds, compound, and condensing. The Buckeye Engine was one of the first in which shaft regulation was used; its governor has already been described and illustrated (see "Governors," p. 422).

The Porter-Allen Engine.

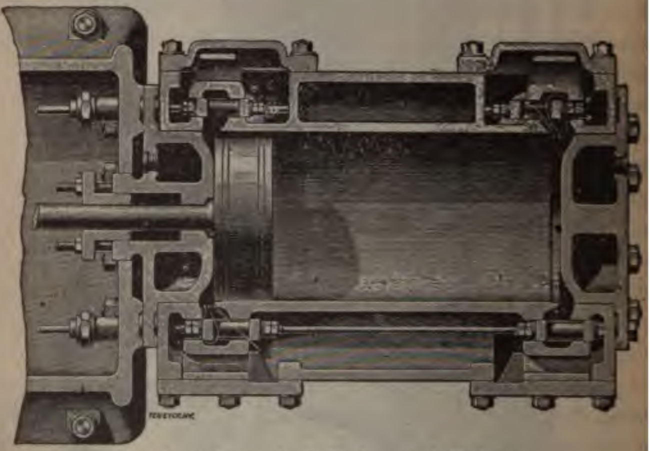
The cut on page 441 represents a front view of the Porter-ı, *High*-speed, Automatic Cut-off Engine, showing the bed-



The Porter-Allen High-Speed Engine.

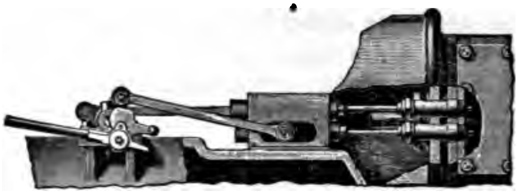
plate, governor, crank, guides, steam and exhaust piping, etc. It will be observed that the bed-plate is of the box form, closed at the top and widened at the base, strongly ribbed, and with a heavy internal flange at the base. The main journal-boxes are carried at one end of the bed-plate, while the cylinder overhangs at the other, being bolted to a circular head cast in one piece with the frame. The whole frame is designed to resist the strains induced by high pressure and high speed, and the engine when running at the highest piston velocities is practically free from vibration, thus keeping the moving parts in alignment and permitting the bearings to run cool without excessive lubrication.

The valve gear and governor, invented by Mr. John F. Alle are worthy of notice, as they constitute a system of steam distribution entirely different from that employed in other types engines belonging to this class. The governor with its eccentr and link motion have already been fully described under "Go *ernors"* (see page 416). The valves are illustrated in the accom *panying* cut, which represents a longitudinal section through


Section through Cylinder and Valves.

ler. There are four valves, two each for steam and exhaust. of the steam-valves is operated by a separate rod, while the xhaust-valves are coupled to a common rod. The motions e valves will be more fully described below. All of the s, as will be observed from the arrows in the cut, open, taneously, four passages to the admission or release of the . They consist of flat plates sliding between their seats, 'pressure-plates" which relieve the steam pressure, pro- g a balanced valve. This feature, together with the fact he rods take hold in the centre line of the valve, insures num and uniform wear both on the valve and seats. The ıst, as already stated, is effected by means of independent s and passages, and therefore the passages through which the enters are never chilled by the exhaust. The economy in se of steam which results from this arrangement and the ment of a variable cut-off without any change in the release ompression, constitute the principal advantages of the "four " over the "single valve" type of engines. In the sectional ıe piston is shown at the beginning of its stroke, and the -valve at the lower crank end has just opened the ports to sion, while the one at the head end is at the extremity of its The exhaust-port at the head end is full open. The press- ıates at the back of each valve are, as will be observed, ed opposite the ports, and these plates are so arranged that will not only relieve the pressure acting upon the backs of ılves, but will also act as relief valves in case there should y water in the cylinder. The steam pressure always acts on plates, but whenever the pressure in the cylinder exceeds n the steam-chest, the plates are moved back until they come ıtact with the cover, thus allowing the excess of pressure to ieved before it can do any harm in the cylinder.

e motion of the valves, will be understood from the cuts ng the eccentric and link on page 417, and the accompany- levation showing *the* valve connections. Referring to the *the rod shown partially* at the left is the one which at its other end is attached to the link-block, the position of which the link is, as will be remembered, under the control of the g ernor. This rod imparts its motion to an arm, as shown, wh motion is communicated by a rock-shaft to two other arms which the steam-valve rods are attached. These arms are se different angles on the rock-shaft, so that one is in a nearly ve cal position and moving its valve with the greatest pos velocity, when the other is almost horizontal and hence impar practically no motion at all to its valve. The object of arrangement is clear. The vertical positions of the rock-s correspond to the opening positions of the valves, which is h accomplished quickly, while the horizontal positions, corresp



Elevation Showing Valve Connections.

ing to those in which the valves are closed, reduce the motic the valve practically to an interval of rest. By this arrangen called a differential valve-movement, the valves are quickly fully opened, while the period during which they are close obtained by a very slow motion, instead of by moving the greater distance at a uniform speed. The exhaust-valve ro attached to a fixed point at the top of the slotted link, so that opening and closing of the exhaust-valves remain invari The admission as well as the cut-off being under control of governor, there is a slight difference in lead for different l and there is at all times a difference in lead at either end of stroke, the latter being proportional to the difference in the pi velocities caused by the angularity of the connecting-rod.

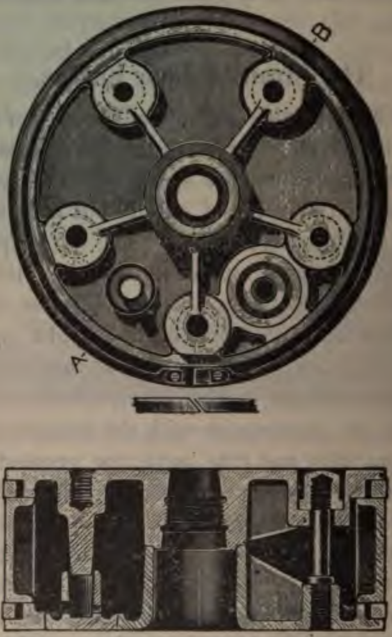
The Porter-Allen was one of the first successful high-

s. It is built by the Southwark Foundry and Machine Co. ladelphia, in sizes ranging from 45 to 2500 horse-power, has met with great success, not only on account of the of its design, but also, largely, on account of the high class kmanship embodied in its construction. Its speed regula- very close, and it is therefore well adapted for electric ıg service.

The Straight Line Engine.

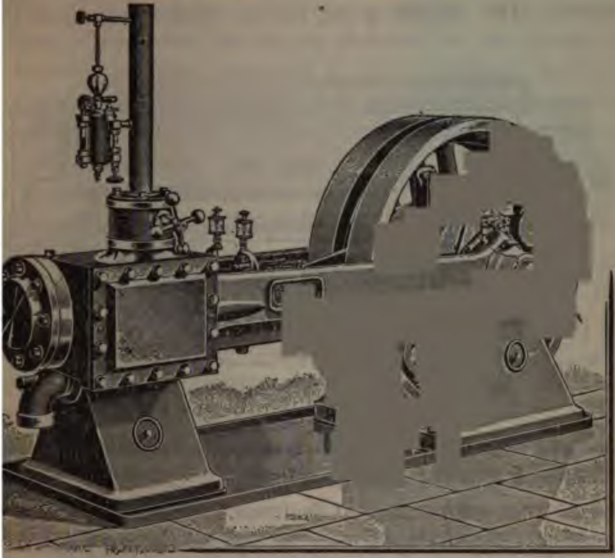
Straight Line Engine was one of the first of the high-speed s in which a single slide valve was used, in connection with t-governor, to regulate the speed under varying conditions d by altering the point of cut-off, but it is now built both ngle- and double-valve engine. The cut on page 447 repre- he single-valve type, and examination of this at once sug- he derivation of its name. Professor Sweet, the designer of ıgine, claims that all strains go in straight lines, and he has the plan of the engine to conform to this idea. All bound- ıes are made straight, ending in curves to avoid corners, and ss-sections are rectangular with the corners rounded. The g arms are wide and thin, with the greatest dimension in rection of the greatest strain. The frame, cylinder, and chest are all cast in one piece, the whole being supported foundation at three points, which has the great advantage he engine remains in perfect alignment, although it is some- more expensive to build than it would be if the cylinders ast separately and bolted to the frame. For re-boring the lers a portable arrangement for mounting on the engine has devised which makes the process of re-boring a very simple

e piston used in this type of engine contains several novel es. In the smaller engines, the packing consists of ordinary rings, but in those of larger diameter than 10″ a different gement is used. *This style of* piston, which is illustrated in *its, has so-called "limited* expansion" packing-rings, whi are made much too large for the cylinder, and sprung in p with some force. They are then pinned in that position and outside turned to a perfect fit in the cylinder. The pin-holes filed in such a way that the rings are free to compress but expand, the result being that they run easily and neither leak



Pop Piston.

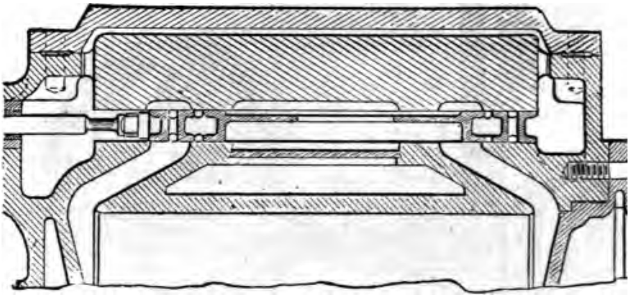
cut the cylinder. The above cut shows also the pop feature, w consists of forcing taper-plugs into the piston from within ward in such a way that it will require a pressure of 200 po per square inch to force them into the piston. If the clear *space is filled* with water, these plugs will be driven into *piston, increasing* the clearance and allowing the engine to r *'til it would* be shut down in the natural course of events gs are again forced out, restoring the piston to its normal on. In the mean time it has been running with an increased ice volume and the slight loss incident thereto.



Straight Line Single-valve Engine.

valve gear is very simple. It consists of a single eccentric l to the boss of the fly-wheel, as already explained (see t Line Engine Governor, page 419) in such a position that ble lead is had. The eccentric connects directly by means d to the valve. The slides for the valve-rod have long g surfaces and are provided with an adjustment for taking wear. The valve, which is illustrated in the accompany-tional cut, is a thin rectangular plate with five openings. essure on the back is relieved by a pressure-plate between *nd its seat the valve slides.* The pressure-plate has open-*it opposite the ports* and rests against distance-pieces in

such a way that an exceedingly minute clearance exists bet the pressure-plate and the valve, thus relieving the pressure at the same time preventing the valve from binding. If any occurs, the distance-pieces may be easily reduced and tigh restored. The double ports in the valves, together with



Section through Steam-chest and Valve.

recesses in the pressure-plates provide ample area for the pa of the steam into the cylinder.

Among the other special features contained in the desig the Straight Line Engine may be mentioned the journals, v contain rings for keeping a constant supply of oil on the be surfaces, the absence of packing in the piston and valve-rods a special design of throttle-valve, in which there is no face ex to steam when the valve is open and when closed none expos rust. The engine is built under the personal supervision of John E. Sweet by the Straight Line Engine Co. of Syracuse, York. Only a limited number of sizes are to be had, and include only simple horizontal engines. They are widely kn and have an established reputation for their excellent work ship.

The Armington & Sims Engine.

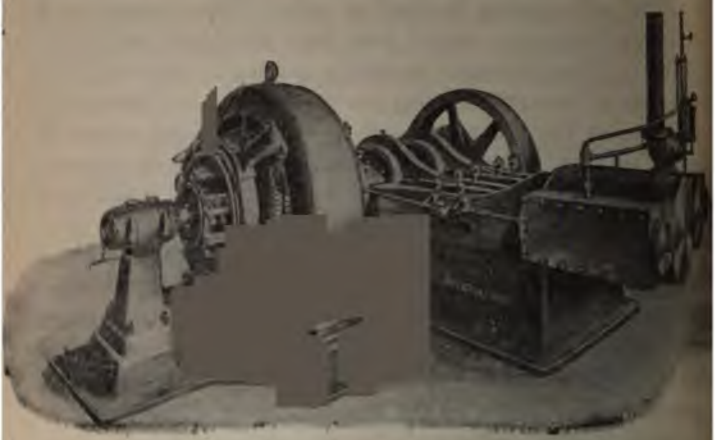
The Armington & Sims Engine, like the Straight Li *ulated* as to speed by a fly-wheel governor used in con

th a single valve. It differs from the latter mainly in the design
the valve, which is of the piston type, which the builders of
is engine were among the first to adopt. The Armington &
ms Piston Valve has already been fully described (see Valves,
ge 399). The governor originally employed consisted of a
ecial form of eccentric having two sheaves, the one placed like
strap around the other, operated by the centrifugal action of
pair of weights. This governor has been discarded, however,
d all of the Armington & Sims Engines are now equipped
th the Rites Governor (see page 422).

These engines are built in a large variety of sizes and designs,
cluding horizontal, vertical, simple, tandem-compound and cross-
mpound. They have been used very extensively in the various
ntral stations of the Edison Companies throughout the United
ates, being belted direct to the generators, and they are now
quently coupled direct to the generator-shaft either by means
a flexible coupling or by extending the engine-shaft and mount-
g the armature spider on the prolongation of the shaft.

Direct connection of engines of the high-speed type to electric
hting and railway generators is a practice which has become
ry general during recent years. It has its advantages and dis-
vantages. Among the former may be mentioned the saving
the floor space, the abolition of belts, and the many sources of
uble and annoyance inherent in this method of transmitting
wer, and the noiselessness with which a direct connected plant
y be made to operate. On the other hand, a generator built
direct coupling to an engine is larger (on account of the
luced speed) and consequently considerably more expensive
an a belt-driven machine of the same output. The plant is
s flexible, because any slight mishap in either the engine or
nerator renders both useless until the trouble is remedied, and
ally, when the armature is mounted directly on the engine
aft, the whole frame of the generator is necessarily in electrical
nnection with the *steam piping,* and hence also with the earth.

The cut on page *450 represents* a 120 horse-power cross-compound horizontal engine of the Armington & Sims type, directl



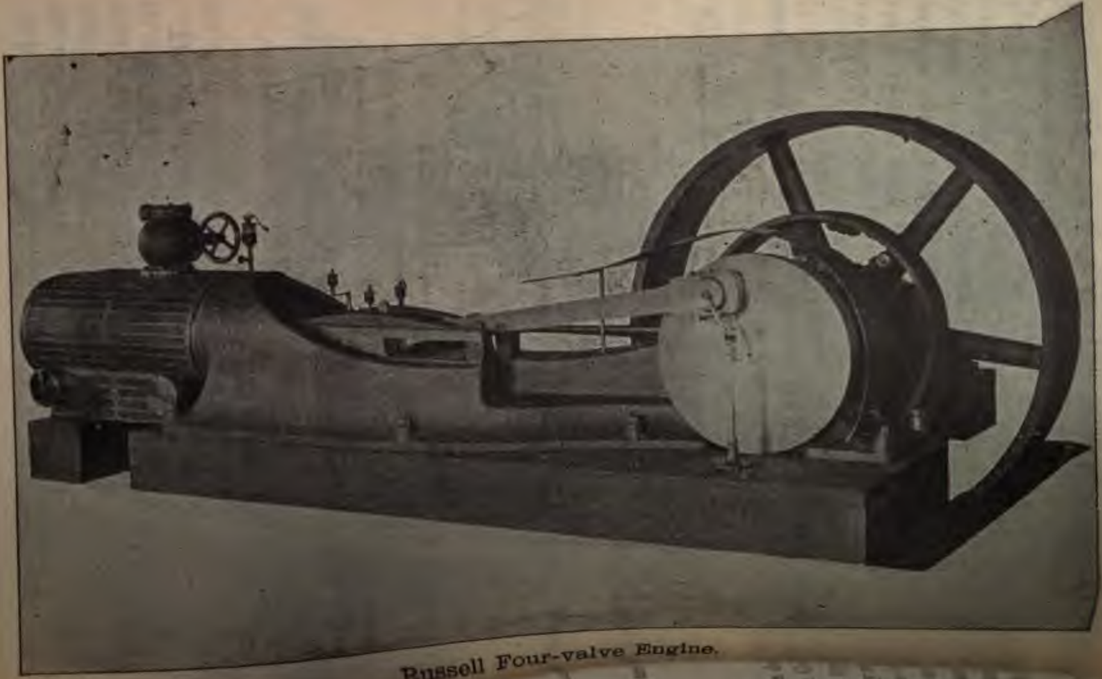
120 Horse-power Cross Compound Engine Directly Connected
75 Kilowatt Dynamo.

connected to a 75 kilowatt dynamo. These engines are built the Armington & Sims Co. of Providence, R. I.

The Russell Four-valve Engine.

The four-valve engine is a type which has been designed combine some of the principal advantages of the Corlis the high-speed engine. It resembles the high-speed type in th the cut-off is varied to meet the changes in load by means of shaft governor, and it resembles the Corliss engine in hav separate passages for the admission and exhaust, thus avoiding th losses inherent in single-valve engines and at the same time ding the advantages to be derived from high rotative s may be had on account of the absence of the rel loss.

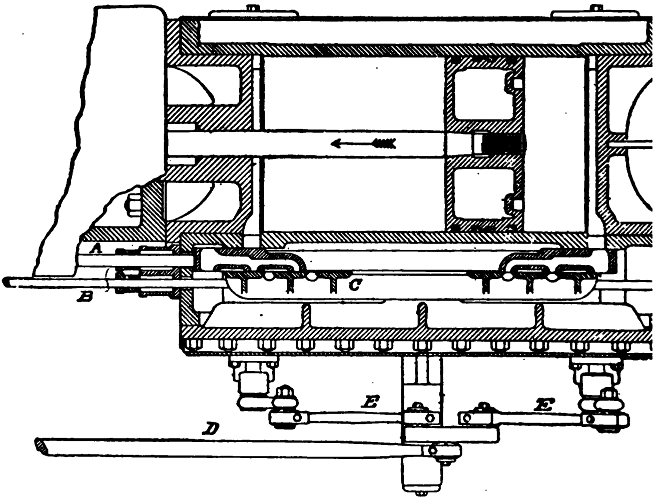
Russell four-valve engine, as will be seen from th



Russell Four-valve Engine.

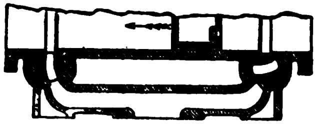
on page 451, is a horizontal side-crank engine with a bed-pl the well-known "Tangye" pattern. It rests on the foundat entire length, and is so constructed that the working par readily accessible. The cylinder is bolted to the bed-plat its outer end is supported but not bolted.

The valve motion consists of two eccentrics, the one fi the shaft, the other controlled by the shaft governor; a



Russell Four-valve Engine. Section through Cylinder and Chest.

plate which receives its motion from the fixed eccentric a parts it to the main valve and the exhaust valves, wh expansion valve receives its motion from the variable ecc This motion is clearly shown in the accompanying cut, represents a section through the cylinder, showing the distri and cut-off valves. The main valve is attached to the r ceives its motion from the fixed eccentric, which exhaust-valve rods E. The expansion valve C notion from the rod *B*, which is connected to the governor. ill be observed that the main valve is of the gridiron type, aining three ports. It is balanced by admitting steam be-n the valve and its seats, leaving narrow bridges for the valve de on. The cut-off or expansion valve rides on the back of main valve. The exhaust valves, which are shown in a sepa- cut, are cylindrical and of the semi-rotary type, their motion g identical with that of the ıust valves in the Corliss type ngines. The method of con-ing the rods to the wrist-plate ch that the valves move rap- at the time of release and ly during the exhaust period. The governor consists of weights counterbalanced by spiral springs so arranged that ı the speed changes the eccentric is rotated around the shaft, ing the angular advance, and in this way the cut-off. It is much like the Buckeye Engine Governor illustrated on page and all that has been said in regard to the latter applies to Russell Governor as well.



Section through Exhaust.

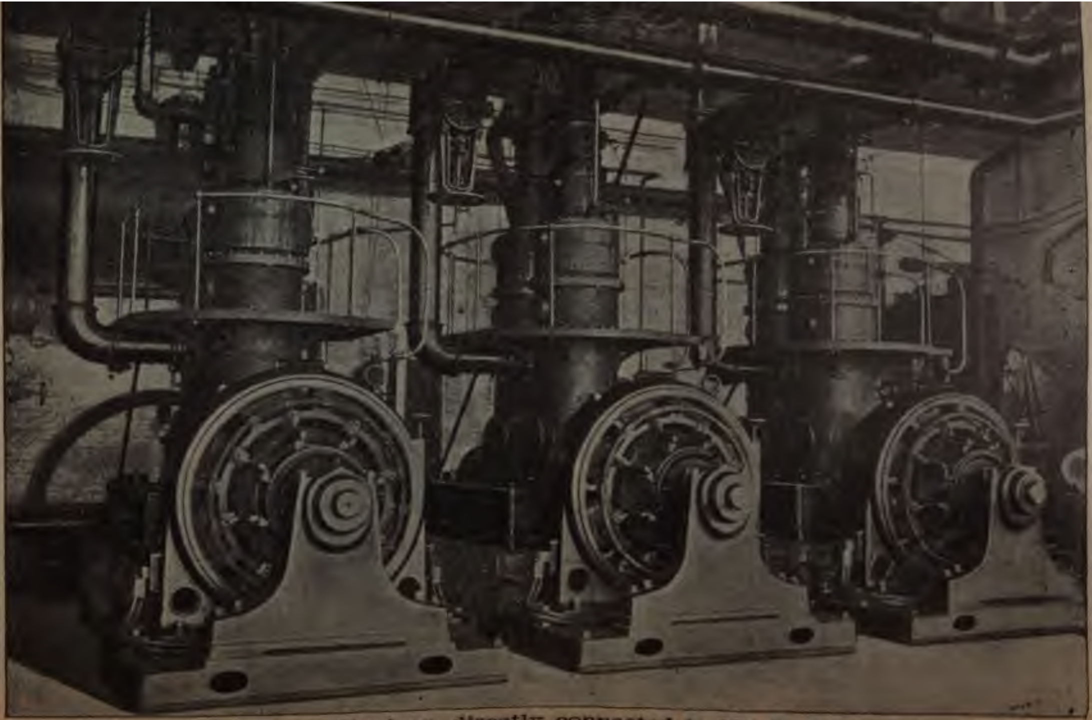
ıe Russell four-valve engine is built by Russell & Co., of ɜillon, Ohio, both as a single and as a tandem-compound en- It is an engine of moderate speed and is well adapted for n connection with electric lighting and power stations. From standpoint of economy it is far superior to the single-valve ne, though not so good as the Corliss type, but it has the ıntage over the latter that it may be run at a higher rotative d.

Single-acting Engines.

he Willans Engine is essentially one of high rotative speed, ying from 470 revolutions per minute in a 50-horse-power unit ın to 270 in an 800-horse-power unit. It is a single-acting ıne of extremely *simple design* with throttling governor and *es placed within the piston*-rods. It is usually built as a compound or triple-expansion engine with two or three sets o cylinders placed side by side, each set containing a high and lo (and intermediate in case of more than two expansions) [illegible] cylinder placed tandem. The economy which has been [illegible] in these engines is quite remarkable, the steam consumption b in some test-cases less than thirteen pounds per indicated ho power-hour. The results which are attained in this respect a due to high speed, multiple expansion, quick cut-off, and [illegible] steam passages. The engine, on account of its high rotative spe is peculiarly adapted for direct connection to lighting generat and the small floor space it occupies when used in this way ma its application very desirable where the available space is limit The cut on page 455 illustrates three of the triple-expansion e gines directly connected to dynamos, the latter having a capaci of 124 kilowatts, each at 380 revolutions per minute. The foll ing description of the engine is furnished by the American build the M. C. Bullock Manufacturing Company of Chicago, Ill.:

Cranks, Connecting-rods, and Eccentrics.—Each line o pistons is connected to its corresponding crank by two exact similar connecting-rods, with a space between, in which wor an eccentric, forged solid upon the crank-pin. The connectin rods work at the top upon two hardened steel pins, so support that the pressure of the rods exerts no twisting strain up them: the eccentric-rod plays in the space between.

Piston-valves are used, moving inside a hollow piston-rod, which passes completely through the line of pistons and throu the ends of the cylinders. The reason the eccentric is on t crank pin, and not on the shaft as usual, is that the valve- (i. e., the inside surface of the hollow piston-rod) moves with t pistons. Consequently the valve-motion required is a moti relative to the pistons, and this is obtained by mounting the ec tric on the crank pin, which, like the piston-rod, moves up n with the pistons. Though its lead is set out differently f an ordinary eccentric, its effect upon the movement of exactly the same.



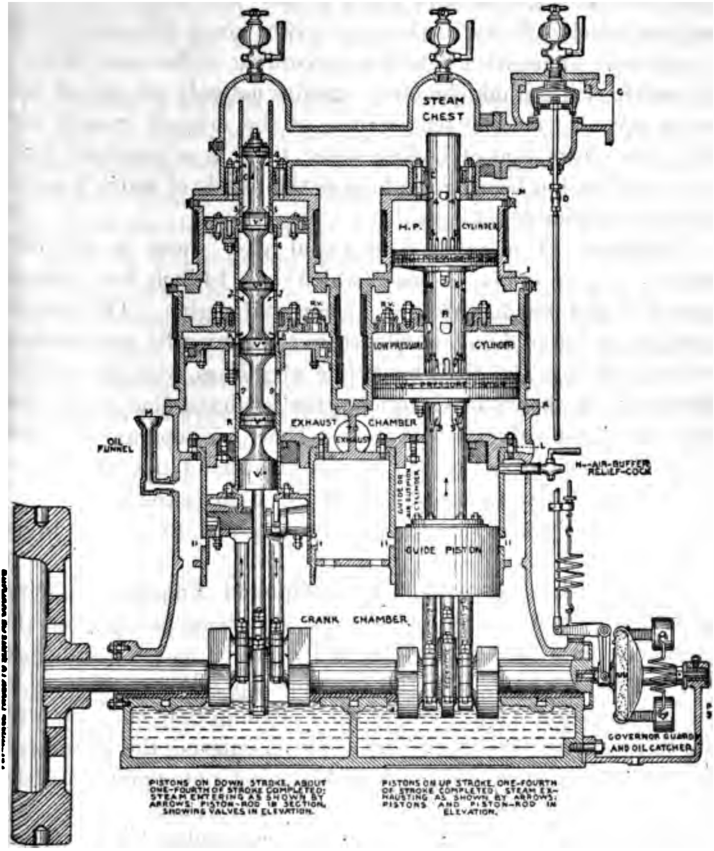
Triple Expansion Willans Engines, directly connected to 124 K. W. Dynamos. Speed

All Parts in Compression—Brasses.—It will be noticed that the upper crank-pin brasses of the connecting-rods are wider than the lower ones. This is because the upper brasses alone are intended to be in actual contact with the crank-pins; the lower ones are only a stand-by in case of accident. All the moving parts of the engine are designed to be strictly in "constant thrust;" the connecting-rods are always in compression, never in tension. From the fact that the upper or working brasses never leave the crank-pins, and so are never exposed to hammering action, however slight, they exhibit great durability when properly lubricated; at the same time it is evident that no wear which can take place in them, however great, can lead to knocking, as the connecting-rods will follow up the wear automatically. But as the lower brasses, to be useful as a stand-by, should not be too far from the crank-pin, the wear should be taken up when it becomes excessive, say as soon as it reaches $\frac{1}{32}$ inch, care being used that the lower brasses are not brought actually into contact with the crank-pin, and that sufficient slack is left to insure an audible knock if the engine is allowed to race, so as to attract attention.

The eccentric-rod is intended to work always in compression, in the same way as the connecting-rods, the holding-down power being furnished by the pressure of the steam in the steam-chest, acting constantly upon the uppermost piston-valve. It may sometimes happen, if the engine is run with a light load but at high speed, that the pressure in the steam-chest (being throttled down by the governor) is insufficent to keep the eccentric-rod in contact with the eccentric upon the up-stroke. If so, a slight knocking may be heard, as the lower eccentric-strap is purposely left an easy fit upon the eccentric (for reasons already explained in the case of the connecting-rod brasses). Such knocking is unimportant, if not allowed to continue too long; it will cease as soon as the engine is given work to do.

A further reason for the moderate wear of the brasses (and eccentric-straps) is that they dip bodily into the lubricant in the

crank-chamber at every revolution. In doing so they splash it over the main bearings and to the upper ends of the connecting-



PISTONS ON DOWN STROKE, ABOUT ONE-FOURTH OF STROKE COMPLETED: STEAM ENTERING AS SHOWN BY ARROWS: PISTON-ROD IN SECTION, SHOWING VALVES IN ELEVATION.

PISTONS ON UP STROKE, ONE-FOURTH OF STROKE COMPLETED. STEAM EXHAUSTING AS SHOWN BY ARROWS: PISTONS AND PISTON-ROD IN ELEVATION.

Vertical Section of a Central-valve Compound Engine

ods and *eccentric-rods,* and into the guide-cylinders as well as *to that part of the hollow* piston-rod where the guide V^1 work constantly in compression—a condition rendered possible only by the fact that the pistons are single-acting, giving no pull to th crank upon the up-stroke, but only a push upon the down-stroke In any engine running at high speed, however, the moving part can only be kept in compression upon the up-stroke by very powerful cushioning, which is rarely obtained in other high-spee engines without excessive compression in the cylinders, involving wasteful use of the steam. Sometimes, when a high-speed engin exhausts into a vacuum, sufficient cushion cannot, by the usu means, be obtained at all. In the Willans Engine very littl compression is given in the steam-cylinders, for little or none i required; the requisite cushioning is obtained independently b special means, the subject of a separate patent. It is in fact pr vided, without the addition of a single moving part of the engin by the guide-pistons. These, on the up-stroke, compress the a contained in the guide-cylinders, and thus any desired amou of cushion can be obtained, according to the clearance allowed.* The work expended in compressing the air is given out again by its expansion on the succeeding down-stroke, and the loss whe the engine is running at good speed is proved by indicator di grams to be too minute to be worth consideration. There are holes 11, 11, in the guide-cylinders, which are uncovered by th guides at the bottom of the stroke. As the casing or chamber which surrounds the guide-cylinders (and forms part of th framing of the engine) is open to the atmosphere, it is eviden that the air compression always commences at atmospheric pressure, and is constant and invariable in its results, whatever alteration may be made in the destination or the pressure of th exhaust steam.

Internal Relief Valves.—In the low-pressure cylinders of all

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* The amount of cushion is fixed in each case to suit the intended speed and may be insufficient to prevent knocking if that speed is largely exceeded. *If for any reason* it is desired to run an engine materially faster than was *originally intended*, and the engine is found to knock at the increased speed *eed must* be reduced until the knocking disappears.

;ines, and in the high-pressure cylinders if large enough to be treated, internal relief-valves are fitted, consisting of a guntal plug screwed into the top of the low-pressure cylinder. e plug is pierced by holes, covered by a single thin gun-metal c. When the disc is raised there is free communication beeen the cylinder and the receiver (or steam-chest) above it. is kept down under ordinary circumstances by the excess of receiver pressure over that in the cylinder; therefore no ing is required, and there is no part liable to get out of order. from water in the cylinder, or any other cause, the pressure es above that in the receiver, the valve lifts, and though the ter is only passed back into the receiver, the relief is found to sufficient, and in fact far more effective than that given by linary external relief-valves. Engines so fitted have been ted by discharging a cubic foot of water suddenly into the am-pipe; also by connecting the steam-pipe with the waterce of the boiler (by a half-inch pipe, with a difference of eighty ınds between the pressure in the boiler and that in the steame)—without any injury to the engine in either case. In cases ere internal relief-valves cannot be used, ordinary external ves are fitted. When an engine is run without load the comssion in the low-pressure cylinder may rise beyond the press in the receiver; the disc of the valve may then be heard to at each revolution, but the noise will go off as soon as the eiver pressure is increased by giving the engine work to do.

\ir Cocks.—Relief cocks are fitted upon the guide-cylinders in ler to avoid compressing the air in them when the engine is ng turned by hand, and to facilitate starting. If the cocks opened at starting, they must be closed again immediately. ey must never be open when the engine is running at speed, or necessary cushion will be wanting. The cocks will be seen at əvel slightly lower than the exhaust-pipe, but they are usually the front of the engine and not at the end, where, for convenie, they are shown *in the lithograph.*

)rain Cocks.*—The drain* cocks on the receivers should be fully opened before starting, and should be kept open for a short tim after starting; they must then be closed and kept closed whil running, except occasionally to draw off any water which ma have collected, when they should be opened only to the smalle extent sufficient to allow the water to escape. The receive drains are connected by copper pipes with the exhaust-chamber.

Lubrication.—Usually only one lubricator is required of t "Sight Feed" pattern. After the engines have worked for so time a very small supply of good mineral oil will suffice for t cylinders. Grease-cups are also fitted, but only as a stand-by, for giving the engine a small flush of oil at starting, or just befo stopping for a long period.

At *M* on the sectional view is shown a funnel for introduci oil into the crank-chamber—preferably the best castor oil, n mineral oil. The funnel (the usual place for which is on t front of the engine, and not where shown) also establishes co munication between the air-cushion cylinders and the atmosphe when the guide-pistons are at the lower end of their strok When water is required to be added it should be poured through the open top of the lubricant gauge—not through t oil funnel.

The quantity of oil required for the crank-chamber is, unde ordinary circumstances, very small indeed, if of the right quality say from one to four pints weekly, according to the size of t engine, the number of hours run, etc.

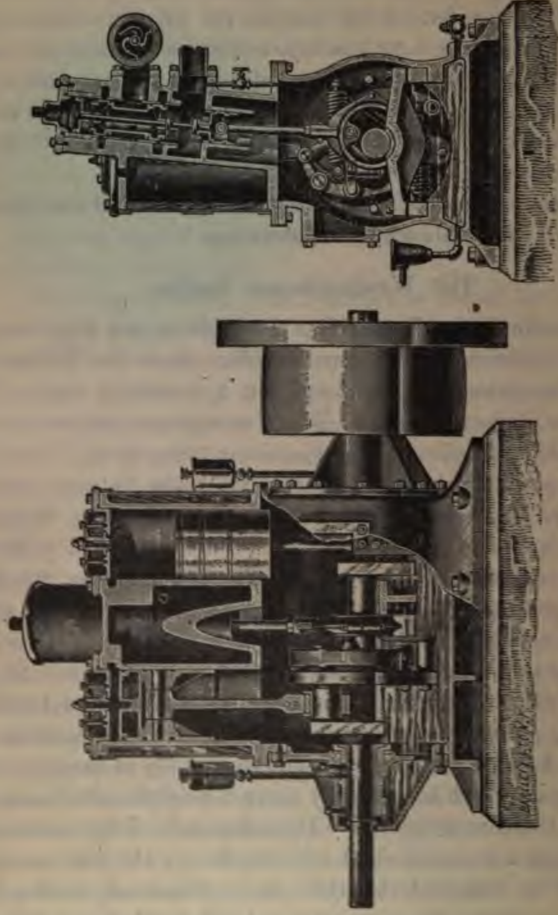
Lubricant Gauge.—(See plate.) The part *X* acts as an ai vessel to prevent violent oscillations of the surface at *Y*. Sinc the gauge communicates only with the lowest part of the cran chamber, very little oil passes into it, and any overflow whic takes place from *Z* consists almost entirely of water. The gaug enables the quantity of lubricant in the crank-chamber to b easily ascertained at any time by the attendant. The norm height at which the lubricant should be maintained is from three-*quarters* of an inch to an inch below the underside of the crank-*shaft.*

Separator.—Every engine is now fitted with a steam dryer or arator mounted on one corner of the bed-plate. The steam ers at the top and descends through a hanging pipe into the dy of the separator. After leaving the pipe it turns upward the exit, which is near the top, while the particles of water, ich are heavier, are shot downward by the velocity with which y leave the hanging pipe. A gauge-glass is fitted, and a drain, cock on which should be so adjusted as to keep a little water the glass just in sight.

Governor.—The construction of the governor and the throttle-lve is sufficiently shown by the drawing.

The Westinghouse Engine.

The Westinghouse Engine, like the Willans, is a single-acting, h-speed, vertical engine, but it differs from the Willans in t it is an automatic cut-off and not a throttling engine. Its ign, also, is very different. The Westinghouse engine is built three different styles called respectively "Standard," "Junior," "Compound," which all embody the main features peculiar this type of engine, differing only in the details. Hence a ef description of one of these, the "Standard," will suffice to w the peculiarities of the engine. The Westinghouse Standard gine, illustrated in the cuts on page 464, consists of two verti- cylinders bolted to the top flange of a cast-iron casing, which s as a pedestal for the engine and also as a receptacle for the ricant, which consists of a mixture of oil and water, into which moving parts dip at every revolution. The pistons contained in se cylinders are acted upon by the steam only at the top, while the bottom, which is open, they carry a wrist-pin which engages end of the connecting-rod. The other ends of the connecting-ls act upon a common shaft with cranks set 180 degrees apart, it will be observed that there is no piston-rod, stuffing-box, sshead or guides, the connecting-rod and crank being the only ks used for *transforming* the reciprocating motion of the piston *the rotary motion of* the shaft. In the smaller engines the cranks and shaft are forged in one piece, while in the larger unit the cranks are forced on the shaft and keyed. The main bearing



LONGITUDINAL SECTION OF ENGINE.

SECTION THROUGH VALVE.

Westinghouse Standard Engine.

are lined with Babbitt metal, and are supplied with a wiper, *shown near* the outer head, which takes up the oil which ked its way past the bearings and returns it to the crank-case. additional bearing is provided near the centre of the shaft for purpose of relieving the shaft of the strain produced by the ist of the pistons.

he valve, which is of the piston type, is placed, in the Stand- Engine, in an oblique position between the pistons, the ports g so arranged that steam is admitted alternately into the two aders, just as in a double-acting, single-cylinder engine it is itted alternately at either end of the cylinder. The valve re- es its motion from an inertia shaft governor placed between cranks, which depends for its action upon the inertia of two hts counterbalanced by spiral springs, so arranged that when speed increases, the throw of a loose eccentric, and hence also ravel of the valve is reduced. The governor has no novel feat- , and it works under the disadvantage, shared by all governors uis class, that the compression and release are altered with the off.

he "Junior" Engine differs slightly from the Standard in de- . The governor is placed in the wheel outside of the casing, the valve-chest is placed horizontally over the cylinders, in- l of between them. In the Compound Engine the high- and the pressure cylinders (each single-acting) are placed side by side. general design, however, and the method of lubricating are the in all. These engines are well adapted for a variety of uses. are especially valuable in locations where the engine is ex- d to dust, since the working parts are almost completely osed in the casing. Its high speed and close regulation make eful also for electric lighting and railway service, although it ot nearly so economical in the use of steam as many of the s of engines which are used for this purpose.

CHAPTER XXI.

INSTALLATION, CARE, AND MANAGEMENT OF STEA ENGINES.

Location of Engine.

The location of the engine is generally the first problem wi which the engineer is confronted. It is a difficult matter to gi any rules which would apply in all cases, as the selection of t best location will depend upon a variety of circumstances. It very important, however, to choose a place upon which a fir foundation may be built, as there is nothing that will so quick ruin even the best-built engines as an unstable foundation. Hav ing made sure of this point, it is best to place the engine in suc a position as to leave ample room on all sides, so that the engi neer in charge may have ready access to all of the parts for lubri cation or any other attention they may require. It is often mistake to locate an engine at the extreme end of a building or long line of shafting, as, if the engine is located to divide th work equally, the strain on the section carrying the drivin pulley will be only one-half what it would be subjected to if th motion were communicated from one end. Engines are frequent so located for the ostensible purpose of economizing space; bu on examination of the surroundings, it will, in a majority of case be found that no more space need be occupied by placing it in th centre. These and similar considerations will determine th best location, but it is generally best to leave this point to so one who is not only thoroughly conversant with the conditio under which the engine has to work, but is also possessed of so experience in the matter of laying out steam-engine plants.

ng decided on the location where the engine is intended t e down from the side of the line of shafting, or count aft, if there be any, to the floor, at three or four different places its length; but if there be no shafting, measure from the side the building to the centre, at five or six points in its length; en strike a line across all these points. This line will show with fficient accuracy the line of the building by which the templet ay be set up; the latter, as shown in the cut on page 468, should a fac-simile, or exact counterpart of the bottom of the bed-plate. may be made of inch pine boards, and set on four props over e excavation, after which it must be squared and levelled with e lines previously taken. The anchor-bolts may now be hung the templet, and the bricklayers proceed with their work. It customary to lay from two to three courses of bricks on the botm of the foundation before the anchors are reached. These cont of plates of cast-iron or old boiler-plate, generally about a foot uare, with a hole sufficiently large for the foundation bolts to p through; though in some instances the anchors extend entirely ross the foundation and take in two bolts each.

Engine Foundations.

Foundations.—A foundation plan, as well as a wooden template r holding the bolts in their proper places while building the ndation, is usually furnished by the builders. If no template furnished, it may easily be constructed from the drawings in e manner indicated in the accompanying cut,* which shows the ndation in the course of construction, with the template holdg the bolts in position. The dimensions for foundations given the builders are usually safe. It is not well, as a rule, to make em any less, and the condition of the ground often makes it cessary to increase the depth of the foundation, which should ways be carried to solid bottom.

Before beginning the foundation itself, a suitable bed should prepared to receive it. The nature of this is dependent upon e nature of the soil at the bottom of the excavation. If this be solid rock or a compact stony soil, it need only be levelled of and the brick-work begun at once. If there is water presen this should be removed by suitable drains, and if there is an indication of a soft soil beneath, which is liable to yield laterall this should be confined by means of piling. If after excavatin to a reasonable depth the soil continues to be of a soft earthy sandy nature, a layer of rubble should be laid and well ramme and on this a layer of from six to twenty-four inches of strong co crete, also well rammed and finished level, to serve as a bed for t foundation. If no indication of solid ground is met at a reaso

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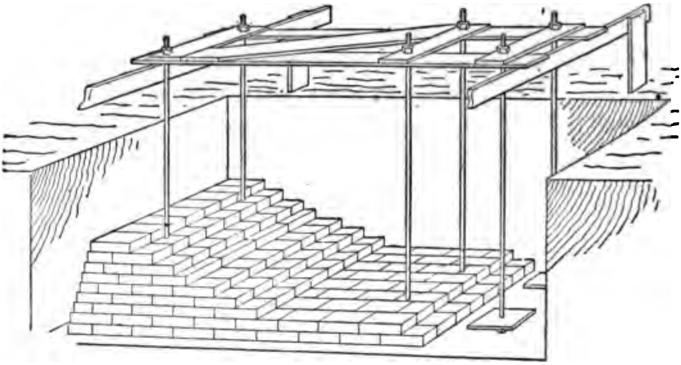
* *From the catalogue of the* Atlas Engine Co. of Indianapolis, Ind.



Engine Foundation in the Course of Construction.

able distance, and the soil continues to be of a yielding or c pressible nature, a suitable bed may be prepared also by driv a sufficient number of piles spaced two or three feet apart, saw them off to a common level, excavating the earth between piles to a depth of two or three feet, and filling the spaces w concrete, finishing the whole to a level for receiving the foun tion.

The materials used in the foundation should be concrete *hard-burned* brick or stone laid in cement. The best foundati *material is a* single solid rock, but this is usually not attaina l a built-up brick or concrete foundation answers all practical rposes. Bricks or stones *should always be laid in clear cement- rtar* and no lime used under any circumstances. This mortar ıuld be made of one part of Portland cement to two parts of an, sharp sand, or nearly in that proportion, with as little water possible. If concrete is used, it may be made in the propor- ı of five parts of hard broken stone, two parts of clean, sharp d, and one part of Portland cement. It is desirable, also, ugh not necessary, to finish off the top of the foundation with apstone.

oundation bolts should never be built solidly into the founda- ı, as the spacing of the holes in the bed-plate of the engine is le to vary, and furthermore if a bolt should break it could not removed if built solidly into the foundation. For these reasons s customary to allow a certain amount of space around the , increasing toward the top. Foundation-bolts should be eaded at both ends, and provided with nuts and washers and hor-plates of ample size to resist the pull. The anchor-plates uld be provided with pockets for holding the lower nuts and vent their turning if it should become necessary to screw them r out.

he foundation should be widest at the bottom, and slope up- ds about 2 inches to the foot, till the level of the floor is hed, after which it may be carried up straight. When fin- d, it may be an inch wider on each side and end than the -plate; after which it should be made perfectly level by means coat of good, strong mortar or cement. A parallel piece of wood, 1 inch in diameter and from 3 to 4 inches wide, made fectly straight on both edges, on which a spirit-level may be ced, will answer for levelling the foundation.

fter the foundation is level, the bed-plate may be placed on it, er by means of a crane, block and tackle, or skids and block- , after which it may be tied down and accurately levelled. It ustomary, *in the case of large* engines, to place wedges between *bed-plate and foundation,* for the purpose of leaving an interstice between the bottom flange of the bed-plate and the bı work, into which melted sulphur is poured. As sulphur is influenced by a change of temperature than any other kn mineral, it is of great value as a bedding for heavy steam-engi and other machinery; besides, when melted, it enters e crevice, and as soon as it is set becomes a permanent fixture. use it, it is necessary to seal the opening between the bed-plate brick work, inside and out, with potter's clay, occasionally lea a gate or "sprue" through which the molten sulphur is pour

A line should next be accurately drawn through the centı the cylinder, and attached to some permanent object at the end of the bed-plate; another line should be drawn at right aı to this through the centre of the main bearing; this latter give the exact location of the off pillow-block, as the crank- must be exactly at right angles with the horizontal line pa through the centre of the cylinder. The fly-wheel may ne swung into the pit, and the shaft slipped through it and fi keyed at the right position, after which the pillow-block may be screwed down, the front head of the cylinder put on cross-head placed in position, the piston slipped in, and the nection between the cross-head and crank-pin made up. (numerous details might be mentioned, but they never all app any individual case, and when any of them present themselv the work proceeds, the remedy in this case must be prescribe the erecting engineer. In setting up engines, like setting vε only general instructions can be given, and it is impossible t down any that would apply to each and every case.

How to put an Engine in Line.

An engine is in line when the axis of the cylinder and ston-rod are in one and the same straight line in all posit is line extended should intersect the axis of the engine-s *and be at right* angles to it. The guides should also be par The shaft must be level, but the centre line of th er may be level, inclined, or vertical, according to the design the engine.

ro "line up" an engine, as it is generally termed, take off cylinder-head, remove the piston, cross-head, and connecting-; then with a centre punch make four (4) marks in the counter-e at each end of the cylinder, at equal distances apart round bore. Take a piece of stiff hoop-iron with a hole at one end t, slip it on to one of the stud-bolts of the back cylinder-head, secure it firmly with a nut, after which it may be bent in the pe of a crank, one end projecting across the cylinder at its tre, at a sufficient distance from it to admit of convenient and ırate measurement. Next draw a fine line through the cylin- and attach one end of it to the temporary crank above men-ed, and the other end to a stake driven into the floor at the k end of the bed-plate. Then with a piece of hard wood or wire pointed at each end and equal in length to half the neter of the cylinder, set the line so that, when one point of wood or wire is inserted in any one of the centre-punch marks ther end of the cylinder, the other end will feel the line. Next if this line passes through the centre of the shaft; if so, the nder is in line with the shaft; if not, one or the other must noved, which requires both skill and judgment, since engines r so much in design and construction. Now turn the engine-t round till the crank-pin almost touches the line passing ugh the centre of the cylinder; then ascertain by measure-t whether the line is equidistant from the collars on the ık-pin. Then turn the shaft on the other centre until the ık-pin feels the line. If the measures correspond, the shaft ı line with the cylinder; if not, they will show which end ls to be moved. The operation may have to be gone over ral times before a definite conclusion can be arrived at. The t may be levelled by placing a spirit-level on it, if there be n; if not, drop a plumb-line passing through the centre of the ık-*pin and shaft; then by* placing the crank at both centres *at half-stroke, the line will* show whether the shaft is level or not. The guides may be brought into line with the cylinder measuring from each end of each guide to the line passing thro the centre of the cylinder, and moving them until they are allel to the line and to each other. To adjust them to the l zontal, a spirit-level may be placed on their top faces. If no l is at hand, a square and plumb-line may be used. Where t accessories are not at hand, a straight-edge placed across t will determine by actual measurement whether they are in with the centre line of the cylinder or not.

Engines get out of line from the following causes: Fault design, faults of construction, overwork, the character of the which they are performing, or from the boss of the crank wea away the face of the main bearing against which it revolves. move an engine-shaft and pillow-blocks into line with the ce of the cylinder, screw down the caps of the pillow-blocks fi on the shaft; then slack up on the bolts that tie down the pi blocks to the bed-plate, after which the shaft pillow-blocks fly-wheel may be moved from the back end by means of a or jack-screw, after which they should be firmly tied and th screws or wedges readjusted. To move a cylinder, if the co tions be short and stiff, remove the bolts which tie it to the plate; then measure from the flange of the cylinder to some object, such as a wall, post, or column; cut a plank or scan about an inch longer than the actual measurement from the inder to the wall, so that when placed against the cylinder it stand slightly oblique; then by driving on the end of the p with a sledge or heavy hammer, the cylinder may easily be m The holes should then be reamed, and new bolts correspondi the reamer substituted for the old ones.

Piping Engines.

In running the steam- and exhaust-pipes it is importa *avoid the* possibility of impeding the free flow of the s *The sizes of* steam- and exhaust-pipes should never be ma ian the outlets provided on the engine. The pipes should be in as straight as possible, and if they are excessively long, say ver fifty feet, a size larger should be used. Horizontal pipes iould be inclined slightly, so as to *allow the condensation to flow* i *the same direction as the steam.* If the steam is moist, it is well provide a separator somewhere in the line, so as to insure dry eam at the engine. If the exhaust is condensed and again used . the boiler, an oil separator should be placed in the exhaust ping (see Separators, p. 281). The steam-pipe should run ertically down to the engine, and provision be made for carrying f the condensation and entrained water. Drips from the steam-pe or separator, cylinder, and valve-chest must be provided with lves, and may be carried into a common drain-pipe. The drips e sometimes connected to the exhaust, but this is not good prac-ce. Steam- and exhaust-pipes when long must be run in such way as to provide for expansion. This may be done either by serting long U-bends, or by laying out the line so that the play the joints at the fittings will allow a certain amount of play in e direction of the length. The pipes should be suitably sup-rted by pipe-hangers, and all live steam-pipes covered with me non-conducting pipe-covering—preferably magnesia. Ex-ust-pipes may be painted if the engine exhausts directly into e atmosphere, but should be covered with pipe-covering when e heat contained in the exhaust is to be utilized. For large zes of pipes long-turn elbows, tees, and crosses are preferable to andard cast-iron fittings.

The principal pipes connected with marine engines and boilers e the main steam-pipe, donkey-pipe, cylinder jacket-pipe, whistle-pe, the steam winch-pipe, ballast engine-pipe, feed-pipes, donkey ed-pipes, donkey suction-pipes, and a hot-well connection-pipe, culating water-pipes, feed suction-pipes, air-pump discharge, ge-discharge, bilge-suction, bilge-injection, cylinder drain-pipes, de-jacket drain-pipes, and steam-jacket drain-pipes, blow-off- and im-pipes, *waste-steam pipe,* cooling-pipe, water-service pipes.

The pipes, cocks, and valves used in connection with the loco-

Whenever an engine is stopped for any length of time, examine all its parts, for the purpose of seeing if they are in good order.

In cases of extreme heating, slack up on the keys and gibs, permit them to run loose for a time, and then take up the lost motion gradually.

Examine the piston-packing in the cylinder frequently, for the purpose of seeing that it is tight and in good order.

Keep the cylinder and steam-pipes well covered with some good non-conductor, to counteract the cooling effect of the atmosphere.

Whenever a clicking noise is heard in the cylinder, open the cylinder drain cocks, and allow the water to escape; then let them remain open until the cylinder works dry steam.

In giving instructions for the care and management of steam-engines, too much stress cannot be laid upon the injunction, "Keep your steam always at the same pressure," as, although all engines employed for manufacturing purposes have governors, they are not always reliable or capable of meeting the requirements of varying steam-pressures and varying loads; consequently, if the steam is, through neglect, permitted to rise above the working pressure, the engine will increase its speed, which will induce a loss of steam, as every revolution above the speed at which the engine was intended to run, and at which the machinery is geared for the manufacture of the different materials, is a waste; and every revolution the engine falls below the regular speed is a loss of production.

Piston-Rod and Valve-Rod Packing, and How to Use it.

Probably no part of the steam-engine is more frequently out of order than the piston-rod and valve-rod packing. This may be attributed to various causes, such as the speed of the engine; whether it is in line or not; whether the piston leaks or not; the condition of the piston-rod; the pressure of the steam; the clear- e in the cylinder, and the character or quality of the material hich the packing is composed, as well as the manner in which applied, and how it is treated afterwards.

the engine is out of line, the piston-rod will crowd the pack- o one side or the other at certain points of the stroke; if the n- and valve-rod are badly fluted, the steam will escape through grooves; if the piston-packing leaks in the cylinder, it will be ssible to keep the packing around the rod tight, in conse- ce of the cushioning induced by the leakage. If the distance een the piston and cylinder-head is not sufficient, the steam escape through the stuffing-box as the engine approaches the es; if the rings of the material are cut too long, they will when screwed up, hug the rod, and, as a result, leakage will r; if too short, the steam will insinuate itself between them, cause leakage; if the material is not of the proper size to fill cavity between the rod and the box, it will leak, however ly it may be screwed up; if the packing is screwed up too at first, the heat induced by the friction will soon destroy its icity, and leakage will be the result; if the engine runs at a high speed, the packing will deteriorate faster than if the d is moderate; and if the pressure is high, the temperature to the pressure will have a tendency to destroy the. packing. ther cause, and indeed one of the main causes which induce ing around piston- and valve-rods, is the want of depth of the ing-boxes of some engines, which will not receive more than rings of packing; as a result, they are continually leaking nd the rod, whereas, if the box is sufficiently deep to admit ur rings, the leakage nuisance would be obviated.

great variety of materials is in use for packing purposes, -stone, paper, india-rubber, asbestos, tin-foil, webbing, wire- , metallic packing, etc., each of which possesses merit peculiar self, but, like governors, and many other important adjuncts e steam-engine, not one of them was ever known to answer y place, or give satisfaction under all circumstances. This s from the fact that our investigation has not been such up e present time, on this subject, as to enable us to decide which material will give the most satisfaction under the most varying circumstances; besides, the best material may be rendered useless in a comparatively short time through ignorance, while an inferior quality may render good service by being intelligently treated.

The following instructions may be of use to those who have not had much experience in packing piston- and valve-rods: Insert as much packing into the box as will just allow the gland to enter; then screw it up solid; after which the nuts should be slacked for the purpose of allowing the packing to swell when exposed to the steam; if leakage occurs, screw them up gradually and evenly, until it stops. If the leakage is excessive, after a sufficient quantity is inserted in the box, do not continue to screw it up, as the heat of the rod will soon destroy the packing. It is always better to stop the engine, if practicable, remove two or three pieces, and replace them again in opposite positions, when in all probability the leakage will cease. Never use any old file or any rough instrument to remove the packing from the boxes, as they have a tendency to abrade or flute the rods, and cause leakage. Every engineer and steam-user should provide himself with suitable tools for removing the old packing from the boxes and inserting the new. To find the proper diameter of the packing for any stuffing-box: Measure the diameter of the rod, and also the gland or stem of the stuffing-box, and half the difference between the two will be the proper size of the packing.

The Causes of Knocking in Steam-Engines.

The most frequent causes of knocking in steam-engines are lost motion in the cross-head, wrist- and crank-pin boxes; looseness in the pillow-block or main-bearing boxes; looseness of the piston-rod or follower-plate; the crank-pin or crank-shaft being out of line with the cylinder, or the wrist-pin, crank-pin, or main-bearing journal being worn oval; the slide-valve having too much or not enough lead; the exhaust opening being too soon or too late; the valve being badly proportioned, or the exhaust passage outlet of the cylinder being contracted.

Other causes are shoulders being worn in each end of the ylinder, in consequence of the packing-rings not travelling over e counter-bore at each end of the stroke; or shoulders being orn on the guides, resulting from the cross-head shoes not overpping them when the crank is at the dead-centre; the piston ot having sufficient clearance at either end of the cylinder, in nsequence of its being altered by taking up the lost motion in e boxes; there not being sufficient draught in the keys to take up e lost motion in the connecting-rod boxes; the packing being rewed too tight round the piston-rod; excessive cushioning, relting from the leaky condition of the piston, which allows the eam to occupy the space between the cylinder and piston-head, the crank approaches the centre, thereby subjecting the engine an enormous strain, as at this part of the stroke the fly-wheel travelling very fast and the crank moving very slowly; or lost otion in the connection by which the slide-valve is attached to e rod. Engines out of line frequently knock sideways at the alf-stroke, but most generally at the outward or inward, upper lower dead-centre, as these are the points at which the greatest rain is thrown on the bearings, in consequence of the direction the connecting-rod having to be reversed. The foregoing causes knocking in engines constitute the principal ones.

The knocks arising from lost motion in any of the revolving, ciprocating, or vibrating parts of an engine may be located by lacing the finger on the part, while the cross-head is being reoved back and forth on the guides by the starting-bar; but nocks induced by the valve opening or closing too soon, by a ntraction of the exhaust, or by the valve or valves being improperly set, are the most difficult to discover, as they are different om those induced by lost motion, the sound being a dull, heavy *ud*, in many instances causing the engine, building, and even the undation to vibrate at every stroke. While an intelligent and reful search will in most cases result in successfully locating the ock, some will for a *time baffle* the most expert engineer. In*nces are not uncommon in* which weeks have been devoted, engines taken apart and put together again, to find a knock, which, when finally discovered, perhaps turned out to be caused by a loose crank-pin, follower-plate, or key in a fly-wheel. It not unfrequently happens that, after every other means have been resorted to, the indicator has to be applied, in order to determine the precise location of the knock or "thud."

From whatever causes knocking in engines may arise, they are a nuisance, which sounds harshly not only to the engineer, but to all who have an *ear* for natural mechanics. Nothing, perhaps, makes the intelligent engineer feel so cheap as to be found in charge of an engine that knocks, as lookers-on are not always capable of deciding who is at fault — the engine or the engineer.

The Remedies for Knocking in Steam-Engines.

While it may be possible in most cases to locate the knocking in steam-engines, and explain the causes from which they arise, it is hardly possible to prescribe a remedy for all, as, in many instances, it must arise out of and be determined by the circumstances of the individual case. The most practical method of remedying the knocking induced by the crank-pin being out of line, is to place the crank-shaft at right angles with the centre of the cylinder, remove the old crank-pin, rebore the hole so as to bring the centre of the new pin perfectly in line with the axis of the cylinder, and replace the old pin with a new one. The knocking induced by the wrist-pin and crank-pin becoming worn oval, may be remedied by filing them perfectly round; but the knocking caused by the crank-shaft journal being worn out of round is very difficult to remedy; in fact, there is hardly any remedy for it, except to remove the shaft, true it up in a lathe, and refit the boxes, which operation is attended with a good deal of difficulty, more especially when the engine is large.

Knocking in the boxes on the crank-pin and cross-head, or valve-rod, may be remedied by filing out the boxes and readjust*ing the keys*, or by putting a liner behind or in front of the boxes, *when there is* not sufficient draught in the keys and gibs. Knock-

ı the steam-chest caused by looseness in the valve connec-
may be remedied by readjusting the jam-nuts or the yoke.
king arising from this cause manifests itself more frequently
steam is shut off from the cylinder, preparatory to stopping
ıgine, than when the engine is running; the lost motion is
up in the valve connections by the pressure of the steam
back of the valve.

ocking in the piston is generally caused by the rod becoming
in the head, and, if it continues for any length of time, it
ys the fit of the rod in the hole. The only practical remedy
such circumstances is to remove the rod, rebore the hole,
ush it or thicken the rod at that point by welding, and fit it
head after the hole is rebored perfectly true. Knocking in
lower-plate is generally caused by the bolts being too long,
n dirt being allowed to accumulate in the holes, which pre-
them from entering sufficiently far to take up the lost mo-
ı the plate, and may be remedied by shortening the follower-
or removing the deposits from the bottoms of the holes, as
se may be.

knocking caused by shoulders becoming worn in the cyl-
at each end can be remedied by reboring the cylinder, and
g the counter-bore sufficiently deep that a part of one of
ıgs will overlap it at each end of the stroke. Knocking
by shoulders becoming worn on the guides can be remedied
ning the guides and making the gibs or shoes sufficiently
ıat they will overrun the guides when the crank is at either
. The knocking induced by any of the foregoing causes is
lly a source of great annoyance to the engineer, as any at-
to adjust the boxes on the cross-head or crank-pin, or the
packing in the cylinder, generally aggravates the cause of
ocking, as any adjustment of the connecting-rod boxes alters
sition of the piston in the cylinder and the cross-head on
ides, and causes them to strike harder against the shoulders.

cking *caused by the* valve or valves being improperly set
remedied by removing the bonnet of the steam chest and

adjusting the valve, so that it may move uniformly on its se thereby giving the same amount of lead at each end of the stro then, if the valve is well proportioned, and the connections tho oughly fitted and skilfully adjusted there is no reason why th engine should knock from this cause. But the knocks arisi from bad proportion in the valve or steam passages are the m difficult of all to remedy, as they are inherent in the machine.

How to Reverse an Engine.

Place the crank on the dead-centre and remove the bonnet the steam-chest; observe the amount of lead or opening that th valve has on the steam end; then loosen the eccentric and turn round on the main shaft in the direction in which it is intende the engine should run, until the valve has the same amount o lead on the same end. To determine whether the lead is exact the same at both ends, a small piece of pine wood may be tapere in the shape of a wedge, and inserted in the port; the marks le on it by the edge of the port and the lip of the valve will sho how far it has entered. The engine should then be turned on the other centre for the purpose of equalizing the lead; the crank should also be placed at half-stroke, top and bottom, for the pur- pose of determining whether the port opening is the same in both positions. When the crank is at half-stroke, the centre of the crank-pin is plumb with the centre of the crank-shaft.

How to Repair Steam-Engines.

It would be reasonable to suppose that any machinist would be capable of repairing steam-engines; and yet, on an examinatio of numerous cases where repairs have been done by persons calling themselves mechanics, it appears that very few machinists are fi to be trusted to do so. A man to be competent to do repairs mus first understand the original character of the engine or machine *and its defects*, whether arising from design, inferior material, o *workmanship*, how an improvement can be made in its workin well as what would be actually an improvement, before pro- eding to make it.

The first step in repairing an engine is to take off the connect- g-rod, cross-head, both cylinder-heads, and remove the piston; en pass a line exactly through the centre of the cylinder, and tach it to some fixed object at the back end, to determine if the ntre of the crank-pin is in line with the centre of the cylinder. not, one of them must be moved, and whichever it is will de- end on the difficulty to be encountered, and must be determined the judgment of the party who undertakes the repairs. The linder must next be accurately measured at both ends and the ntre, for the purpose of determining if it is worn larger in the ntre than at either end, or worn oval, as is often the case.

In either case it will be necessary to rebore the cylinder and ake it uniform all through. It is next necessary to caliper the ss-head, wrist- and crank-pin, to see if they are worn oval, and so, they must be filed round. The guides should then be tested ith an accurate parallel piece, to ascertain if they are straight l through; if they are hollow in the middle or at either end, ey must be taken down and planed straight. If the piston-rod badly fluted, it must be put in a lathe, returned, and filed; the ngs should be taken off, placed in a lathe-chuck, and faced up both ends, and if they are cut they should be turned true and ooth. The cross-head should then be measured crosswise to termine whether the guides are too far apart or not; and if so, e holes in the studs which tie them to the bed-plate must be ed oval to bring them to a proper position. If the valve and at are cut, the valve must be taken off and planed in the oppo- e direction to its travel. The steam-chest must also be removed, d the valve-seat straightened by filing and scraping, after which e valve may be carefully fitted to it.

The flange of the piston-head and follower-plate should be faced in a lathe, at the point where they strike the rings, and the lat- should be *carefully ground* and scraped on to them. The piston *uld next be inserted into* the cylinder, set out, and the cross-head slipped on, connected with it, and levelled, so that it may stand parallel with the centre of the axis of the cylinder at all points of the stroke. The connecting-rod boxes should be examined in order to ascertain if they are "brass bound," and if so, they should be filed out. The main pillow-block bearing should receive attention, in order to determine if it is worn oval or loose. In fact, every part should receive attention, because defects that have not been thought of may be revealed as the work progresses. It has been generally heretofore supposed that any one bearing the name of a machinist is competent to repair a steam-engine, which, of course, is a grave error, as thousands of mechanics fully competent to build a machine are totally unfit to repair it.

This arises from the fact, that the repairing of steam-engines and other machinery requires a different class of talent from that necessary to build them. A machinist may be a good hand on either a vice, lathe, or planer; he may be a thorough fitter and a neat finisher, and yet he may lack that keen observation, that cool, patient, and searching perseverance which are so essential in the party that will become an adept in the repairing of steam-engines and other machinery. It not unfrequently happens, that when everything has been done that was considered absolutely necessary, an engine works badly when started up, which is very discouraging to any one, except those who take a peculiar interest in ferreting out the causes of minor defects which have been overlooked when the more prominent ones were remedied. Almost any one can tell if an engine is badly out of line, the cylinder fluted, or the crank-pins loose or worn oval; but it requires a different kind of talent to determine the different causes for the defective working of steam-engines, and prescribe a remedy for them, as many of them apparently did not exist at the commencement of the work, but cropped out as it progressed. One of the greatest mistakes in the repairs of steam-engines and other machinery, is that those who have them in charge are expected to perform the work in too limited a time. This being impossible, the only resource left is to slight it.

How to Increase the Power of the Steam-Engine.

It frequently happens that engines which were originally of ufficient power to do the work of a manufacturing establishment, become unable to do the work, owing to an increase in the busiess; and while the cost of replacing an engine with one of suffiient power would be a matter of nominal consideration, the time xpended in removing and replacing it with a larger one might nvolve a serious loss to the owner. Under such circumstances, the ost practicable ways to remedy the difficulty for the time being ould be—*first*, to raise the pressure, providing the boiler is conidered safe; *second*, to increase the speed of the engine; *third*, to eplace the old cylinder with a new one of larger diameter, which ould, of course, involve the necessity of a new piston, steam-chest, nd valve; *fourth*, to compound the engine by adding a low-pressure cylinder with suitable changes in the valve-gear; *fifth*, to add condenser, if the engine originally ran non-condensing.

For a moderate increase in power, the last plan would be the ost safe and practicable, as the active condition of steam-boilers s not always understood, and without a thorough knowledge on he subject it would be unwise to increase the pressure; nor should ny engine be run at a higher speed than it is capable of standng without springing or shaking to pieces. The increase in power hat would result from replacing the old cylinder with a new one wo inches larger in diameter may be illustrated as follows: Take, or instance, a 10-inch cylinder, which contains 78·54 square inches n area, while a cylinder 12 inches in diameter contains 113·09 quare inches, which makes a difference of 34·55 square inches in he piston. Now, if the engine having a 10-inch cylinder was nable to do the work with 60 lbs. pressure per square inch, it ould do the work easily with the 12-inch cylinder at the same ressure, as the new cylinder would make a difference of from 5 o 6 horse-power. Measures might be taken, and the new cylinder, *piston, and steam-chest* prepared and placed in position at a *ven time, without causing* any interruption to the business.

Of course the margin for increasing the size of cylinder for any engine, and using all the other original parts of the engine, is limited, and should never exceed 2 inches; as, to exceed that limit, the other parts would be too light, and become liable to spring. To increase the speed of an engine, it would be necessary to have a new counter-pulley, so that, while the piston velocity is increased, the speed of the shafting may remain the same. An engine will develop more power by increasing its speed, but will use more steam, and as a consequence more fuel will be consumed. The overtaxing of steam-engines and boilers, or any other class of machines, is sure to induce waste either in fuel or wear and tear; but there are circumstances under which manufacturers and steam users find themselves placed, in which it would be impossible to avoid waste. Steam-engines or boilers, or any other class of machines that is too large or too small for the work to be performed, are not economical.

The Dead-Centre.

All reciprocating steam-engines have one dead-centre in each stroke and two in each revolution, and that point is the point at which the steam is exhausted, and the centre of the crank-pin is parallel with the centre of the axis of the cylinder. The centre of the cross-head, in some cases, may be above or below the centre of the cylinder; but by placing a spirit-level on the top or bottom of the stub-end strap, the dead-centre may be easily found. The experienced engineer or machinist can generally tell by the eye when the crank is at the dead-centre; but to insure accuracy it is always better, in the case of horizontal engines, to try it with a level, and in vertical engines with a plumb-bob and line. The cranks of all engines have to be placed accurately on the centre when the valves are set.

A single reciprocating engine is completely helpless when the crank is at the dead-centre, and would stop there if it was not for the momentum of the balance-wheel. Double reciprocating en-s, such as locomotives and marine engines, which have their ıks set at right angles, require no balance-wheel, as they pull ı other off the dead-centre, in consequence of one crank being ts full-power point while the other is at the weakest. There some engines, such as the rotary, which have no dead-centre ıeir revolution.

tting the Cranks of Steam-Engines to their Shafts.

oring the hole for the shaft in the crank is not so easy a task ıe average engineer would suppose. Theoretically, when the is bored in the crank, if the boss is faced true, and then bolted true face-plate on a lathe, it must be true. But inaccuracy ıently arises from the fact that there are few face-plates which rue, and continue to remain so for any length of time. And when the boring is as well done as can be expected under ircumstances, the crank is frequently thrown out of line in ng it on the shaft. For this reason, no crank should leave works where it was made without being tested after having keyed on.

hen the crank is in the form of a disc, or wheel, the best is to turn it true, first on a mandril, and then so fit it to the t, and the key to its seat, that after the keying it will run ; but with the ordinary crank, this cannot be so easily done, ll the surface available for testing its truth is near the centre; ıch cases, the main reliance must be placed in fitting the key as as the crank itself to the shaft. The key should never be finally en till it has first been frequently partially driven, its points ntact filed or scraped, and it fits perfectly its whole length.

he essential conditions necessary for the production of a well-ıg and durable crank-shaft journal are, good material, a stiff, ng lathe, a skilful machinist, and a sharp, well-tempered, and ectly set tool. The finishing cuts should be light, and, if it ıot be made sufficiently smooth with the tool, it must not be l, but *may be ground and* polished smooth by blocks of wood, *copper, or some other* suitable material fitted to the journal in such a manner that the imperfections left by the turning-to will be corrected instead of aggravated by the use of a file or e of a stick, as is commonly the case. The polishing powder use should be very fine; emery is considered, by many, objectionable fo polishing wearing surfaces, but on good homogeneous material, fre from flaws, fine emery may be used without any injurious effects.

Duplicating the Parts of Steam-Engines.

Duplicating the parts of any class of machines is an advantage, as it insures more uniform proportions in their original constru tion than could otherwise be obtained, as the term duplicatio of parts conveys the impression that they are made to standa gauges, and for any number of machines must retain the propor tions of the original. While duplication of parts is convenient and sometimes of great value in cases of emergency, it is rarely so in case of repairs; since, as soon as any journal or bearing i put into use, its dimensions begin to change, the cylinder commences to enlarge and the piston to diminish. This change of shape extends to the piston-rod, and glands of the stuffing-boxes, wrist-pins, crank-pins, rocker-shafts, etc. The eccentric wears flat on two sides, in consequence of the thrust at these points, and the straps wear flat, owing to the push and pull at two points.

Now how can it be expected that a new eccentric will fit the old straps, or the new straps conform to the old eccentric, or that the new piston will prove a good fit for the old cylinder, or the new piston-rod for the worn-out gland? If the crank-shaft becomes worn oval, it will not adjust itself to a new main-bearing made from the original standard; or if the crank-pin becomes worn tapering, owing to the engine being out of line, a box made of the original proportions will not drop into its place and work harmoniously; but, as before stated, in case of emergency, such as break-downs, or where interruption to business would entail great loss, duplicate parts are a tolerably good make-shift, and that is *all that can* be said in their favor. For this reason, the duplica*tion of parts,* which in case of breakage would be most likely to

sable a machine, ought to be encouraged, especially in case of
arine engines, locomotives running in sections of the country
here there are no repair shops, and stationary engines located
isolated places.

QUESTIONS.

What constitutes a steam engine? What is the simplest form
steam engine?

Name and describe the principal parts. What is the function
each?

Who was the inventor of the steam engine and in what par-
ulars does a modern engine differ from the first forms?

How is the power of engines expressed? What is the differ-
e between indicated and net horse-power?

What four factors determine the power of an engine? Explain
rule for calculating horse-power.

What is the horse-power of the following engine?

Cylinder, 18 × 20.
Steam pressure, 100 pounds.
Cut-off, ¼.
Speed, 200 R. P. M.

At what speed would the above engine develop 300 horse-power?

Required the diameter of cylinder of an engine to develop 300
se-power at a piston speed of 600 feet per minute and mean
ctive pressure of 55 pounds per square inch?

Write out a formula for calculating the stroke of an engine
n the horse-power, mean effective pressure, piston speed, and
meter of cylinder are given.

Write out a formula for mean effective pressure in terms of
neter of cylinder, stroke, speed, and horse-power.

How are steam engines classified?

xplain what would be meant by a vertical, triple-expansion,
speed, single-acting, non-condensing automatic cut-off, sta-

tionary engine. Which of the engines described in Chapter X would answer to this description?

What are the advantages of high piston speed? What ki of service requires high rotative speed?

Explain, briefly, the advantages to be derived by properly p portioning the reciprocating parts of an engine. Illustrate b diagram.

Why must high-speed engines run under high pressure?

What is the difference between condensing and non-conden engines?

If the vacuum in a 14 × 20 condensing engine running at revolutions per minute is 26 inches, what is the gain in power to the condenser?

What advantages are to be derived from compounding? W is the difference between a tandem and a cross compound engi

Explain the difference between throttling and automatic off engines. Where are throttling engines used?

In what respects do stationary, marine, and locomotive eng differ?

How is the power of locomotives measured?

What are rotary engines? Why are they not used more tensively?

What are the principal sources of loss in steam engines?

Calculate what percentage of the energy contained in the f is utilized in steam plant consisting of a boiler which evapor eight pounds of water per pound of fuel, and an engine wh consumes twenty-five pounds of steam per indicated horse-po hour if the coal contains 10,000 heat units per pound.

What is the principal source of waste in the engine prop How may it be reduced?

Which is the most economical type of engine and why?

What is the function of bed-plates and housings? How sho they be built?

Make a sketch showing the usual design of steam cylinders and the principal features.

at is the cause of cylinders wearing unevenly? How can it
ided?
v calculate the area of the steam passages?
at is meant by clearance? Why is it a necessity and how
be determined in a given engine?
at is the object of jacketing steam cylinders?
lain the use of the piston and the usual methods of con-
on.
e a sketch showing piston, connecting-rod, and crank con-
s.
e the rule for finding the distance the piston is ahead of its
l position when the crank is in a position perpendicular to
tre line of the engine.
at considerations determine the length of connecting rods?
ong are they usually made?
at is the function of the cross-head?
lain the difference between "throwing over" and "throw-
der."
e a sketch showing a connecting-rod end and explain how
justments are had.
at are the three different forms of cranks? Where would
e used?
at are the disadvantages of centre cranks? Of what mate-
e they usually constructed, and why?
may we determine whether or not the crank-pin is in
th the centre line of the cylinder?
at is an eccentric? In what respect does it differ from a
When is it used in preference to a crank, and why?
lain what is meant by "throw" of an eccentric.
ulate the diameter of a steel shaft which will safely trans-
0 horse-power at 100 revolutions per minute.
at is the function of the fly-wheel? Where should the bulk
veight be concentrated? Make a sketch showing how a
el may *be constructed* when the rim, hub, and arms are
arately.

Does it make any difference whether a fly-wheel is evenly balanced?

Explain the terms: "Valve gear," "releasing valve gear," "automatic cut-off," "positive cut-off," "riding cut-off," and "reversing gear."

What are "relief valves," "balance valves," "rotary valves," "semi-rotary valves," and "gridiron valves?"

Explain by diagrams the action of the plain slide valve.

Define the terms: "Admission," "exhaust," "cut-off," "expansion," "compression," "angle of advance," "travel," "over-travel," "inside lap," "outside lap," "steam lead," "exhaust lead," and "negative lead."

Given the throw of the eccentric, angle of advance and inside and outside lap, show how by the Zeuner diagram the distribution of steam may be studied.

Explain how to set the valves of steam engines.

Explain how the lap and lead may be determined without opening the steam chest.

Why are plain slide valves not used with large engines and high pressures?

Describe the piston valve and state its advantages and disadvantages as compared to a plain slide valve.

Make a sketch of valve and steam chest showing how the pressure against the valve may be relieved.

What is meant by a poppet valve? How is the lift determined?

What is meant by a variable cut-off gear?

Explain the Stephenson link motion and illustrate it by a sketch.

Explain the Meyer valve gear and make a sketch showing how it might be used as an automatic cut-off gear. Why is it not used more extensively?

What is the function of the governor? Explain the action of a simple throttling governor.

What are the principal defects of throttling governors?

Why is shaft regulation used so extensively with high-speed nes?

ain the action of a simple form of fly-wheel governor.

ɜ sketches and explain the action of the following forms rnors: Porter-Allen, Ball, Buckeye, and Ritos.

t is the effect on the steam distribution if the cut-off is by altering the angular advance only or the eccentricity

ıat form of valve gear is it not necessary to vary both the advance and the throw of the eccentric?

calculate the diameter of governor pulleys?

t is the maximum variation in speed which a good shaft ır should allow?

does the governor act in the Corliss type of engines?

ːibe the Corliss engine and state why its economy is greater e slide-valve engine.

ain by a sketch the releasing mechanism employed in the Corliss engine.

t is the function of the dash pot? Why is it better than ꞔ in connection with Corliss gears?

ıat respect does the improved Greene engine differ from liss type?

can Corliss engines not operate at high rotative speed?

t are the characteristics of high-speed automatic cut-ines? For what class of service are they especially .?

t is the steam consumption per horse-power hour in this engines?

ain the method of regulating the speed in the Buckeye ːter-Allen engines. Which of the two should, other things ɟual, be the more economical in the use of steam?

ain the use of pressure plates for relieving slide valves of m pressure on their backs.

t advantage is derived from the differential valve motion in the Porter-Allen engine?

hat *essential respects* does the Straight Line engine differ *Buckeye?*

Explain the use of the "Pop Piston" in the Straight Li engine.

What is meant by direct connection of engine and dynam How is it accomplished? What are the advantages and dis vantages of this practice?

Explain what is meant by a "four-valve" engine and why it more economical than a "single-valve" engine.

Make a sketch showing how the steam is distributed in Russell four-valve engine and also how the speed is controlled.

What are the advantages and disadvantages of single-acti engines?

To what features in the design of the Willans engine is increased economy in the use of steam due?

Explain the peculiarities of the Westinghouse engine.

What considerations should determine the location of engin

What materials should be used in the construction of foun tions?

Make a sketch showing how foundation bolts and anchor pl should be made, and explain how they are held in position wl building the foundation.

Under what circumstances should piles be driven beneath foundation? How should they be spaced?

How should horizontal lines of steam piping be installed?

How are long lines of pipe run in order to allow for expansi

Explain how to set up an engine after the foundation is rea

What is the cause of engines getting out of alignment?

Name the principal pipes used in connection with mar engines.

Explain the use of piston and valve-rod packing. What m rials are used for this purpose?

What are the most frequent causes of knocking in ste engines? How may knocks be located? What are the reme for different kinds of knocks?

Explain how an engine with a fixed eccentric may be revers

ow may the power of a given steam engine be increased?

PART VI.

STEAM-ENGINE APPLIANCES.

CHAPTER XXII.

THE STEAM-ENGINE INDICATOR.

o device, in the entire range of mechanical inventions,
much in developing and perfecting the steam-engine
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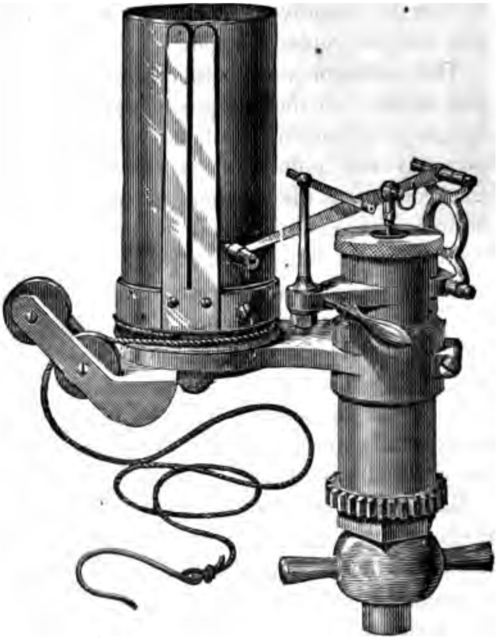

n-engine indicator, like many other accessories of the
e, dates back *to the time* of James Watt, although the
used at the present time has undergone so many

changes in construction that it can hardly be recognized a same device. Be this as it may, Watt's indicator thougl perfect, answered for engines travelling at a piston speed of s 150 feet per minute, and for pressures averaging 7 lbs. a atmosphere, which he thought was the fastest speed and the hi pressure that would ever be needed. But experience soon de strated that the highest economy was attained with high p speeds and correspondingly high pressures, and, as a r Watt's indicator proved to be unsuitable for these condi The requirements of such an instrument were more fully a ciated by McNought, of Glasgow. The world is more ind to him for improvements in the steam-engine indicator th any one previous to his time.

The indicator was further improved by Hopkinson, Stil and others; but these improvements were not in the mech design or arrangement of its working parts, but rather i accuracy and refinement of the workmanship employed construction, as the mechanical principles embodied in the indicator were continued in them all. They consisted of a right cylinder, into which a piston was accurately fitted. T piston-rod a spiral spring was attached, to resist the steam a vacuum when acting against it. The pencil was also attacl the piston-rod; the result of which was that the piston, pisto and spring had the same movements as the pencil. Witl instruments the vibration of the piston was so great as to r them totally unreliable with fast running engines, or when was worked expansively.

Gooch was the first inventor that gave the pencil a g range of movement than the piston. In his instrument th inder was placed horizontally, and when its piston was sub to pressure it compressed two elliptic springs. The top o piston-rod was connected to the short arm of a lever, to the arm of which the pencil was attached, thus giving conside more motion than could be obtained by any former instru moved in the arc of a circle instead of a straigh

am was traced on a web of paper while it was unwound
lrum and wound upon another. This arrangement ad-
a succession of diagrams being taken without any in-
manipulation of the instrument. The communication
he indicator and
cylinder was closed
valve instead of a
it as the principle
ng steam expan-
came almost uni-
instrument more
han any of these
mentioned be-
necessity of the
l such was found
chards' Indicator.
istrument the fol-
istruction and pro-
ave been adopted,
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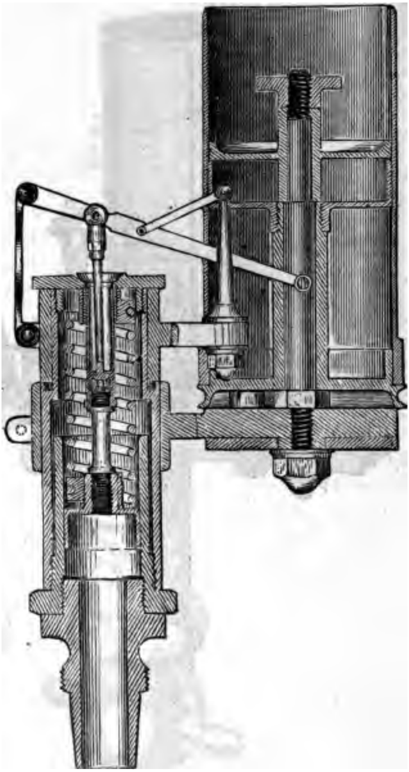
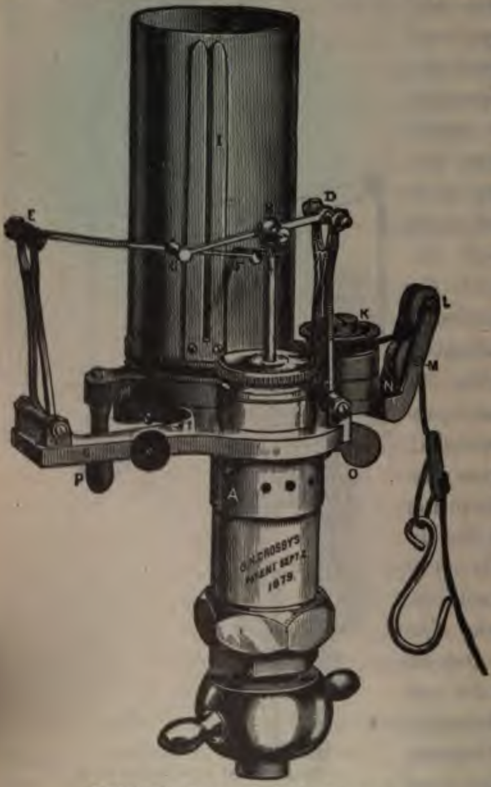
area of the piston
uare inch, the di-
f which is very
of an inch, or,
tly, ·79 inch. The
the long arm of
to which the rod
ton is attached, is
and the distance
pivot of the lever
nt of attachment of the piston is ¾ of an inch, thus giv-
ee end of the lever, and with it the pencil, four times
ment of the piston. The secondary lever is equal in
the first, *and the link* which connects the two, and which
pencil at its centre, is 1·⅞ inches long. These propor-



Section of the Indicator.

tions give a practically straight pencil movement for a di
of 2½ inches.

The indicator was further improved by Harris Tabor
of whose instrument may be seen on pages 503 and 50



Crosby's Improved Indicator.

more rece
provements
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been effec
George H.
a mechanic
gineer of
Mass. It h
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of Mr. Cr
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manipulati
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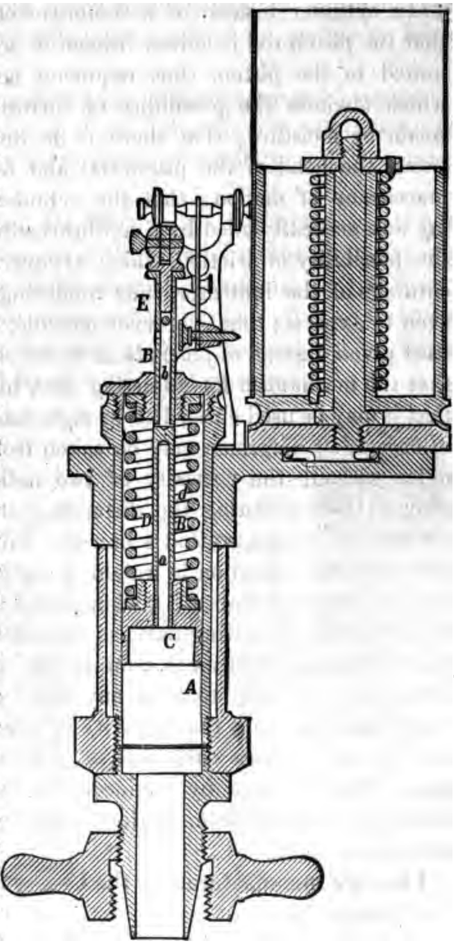
partially su
as the Crosby Indicator is an improvement, in some r
'er devices of the kind in use. It is reliable
, whether employed for taking diagrams fro
-off, throttling, simple, compound, fast- or

ıg engines and it is free from some objectionable features other instruments, ıich render the diaams taken by them roneous. In the conption of this instruent, the inventor seems have predetermined any of the circumances, emergencies, ıd requirements that ight possibly arise in e use of the indicator, d provided for them.

The advantages of Crosby Indicator e, that the parallel otion is not a geometal approximate imiion of, but a true otion; that the motion the pencil is a unim multiplication of piston of the indior, and is solely conolled by the motion the piston-rod; that ere are no guidingts, either straight or rved, to induce fricn; that there is no mpensating arm inted to any fixed int, as in other *indicators; that* the pencil is located close to *piston-rod, instead of* projecting several inches to one side,



Section of Crosby's Indicator.

as in other cases; that an air-chamber or jacket surround
steam-cylinder instead of a steam-jacket, as in other insta
that the piston-rod is hollow instead of solid, and that it is s
united to the piston, thus requiring no joints below the
which obviates the possibility of corrosion by the action
steam or moisture; that there is no link or connecting-b
tween the head of the piston-rod and lever to cause fricti
inaccuracy of motion; that the cylinder, piston, and pist
are automatically oiled by a self-lubricating device, thus rem
the possibility of friction, which always induces error in t
cordings of the indicator, thus rendering the diagram dec
even to experts; that, wherever possible, every joint is mad
steel pivots instead of journals, as is the case in other instru
that the mechanism for adjusting each instrument is so arr
that it may be used either left- or right-handed, as the case m
in order that diagrams may be taken from either end of t
inder without the necessity of two indicators; that mea
provided for adjusting the distance that the paper shall
towards the pencil, so that a hair-line can be drawn withou
tion; that the reduction in weight in the piston and hollow
rod and the refinement of workmanship in the levers and
render the reciprocating parts so extremely light that mom
and friction are reduced to a minimum; that it is more easi
justed and operated than in any other instrument of the
thus dispensing with the necessity of experts, and that dia
may be taken from each end of a steam-cylinder witho
least difficulty, even by engineers of ordinary intelligenc
limited experience, from engines running at the highest p
able piston speed.

They are manufactured by the Crosby Steam Gauge and
Co., Boston, Mass.

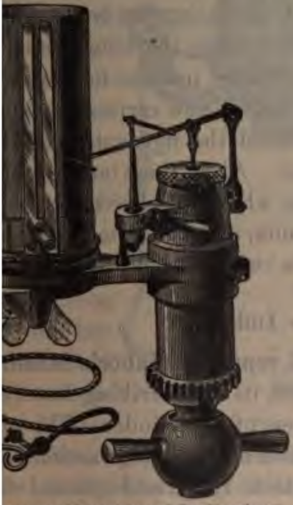
The Thompson Improved Indicator.

hompson Indicator, see page 501, improved and pa
Thompson, of Salem, O., is another instrume

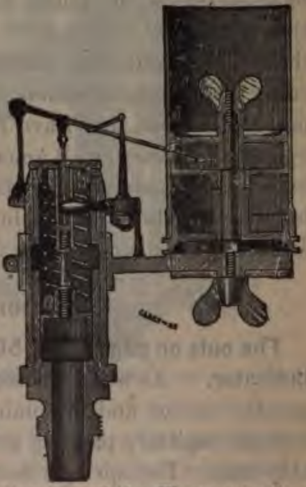
ised on high-speed engines with success; and it works well on slow- and quick-running engines. It will give esults under any attainable speed of an engine or loco-

doption of high-piston speed of stationary and locomotive as created a demand for an indicator that will take cards high speed, say three hundred revolutions per minute, nore.

be observed that Mr. Thompson's improvement mainly n reducing the weight of the parallel motion, by lessening per of vibrating pieces, thereby decreasing the tendency vavy lines in both steam and expansion. By this arrange- instrument is lighter and more compact,—qualities which lly appreciated by all intelligent engineers.



mpson Improved Indicator.



Section of the Thompson Improved Indicator.

ingenious device, invented by Mr. Thompson, cards can with *this instrument at* a pressure as high as five hundred *the square inch.*

The Thompson Indicator is manufactured by the Ameri Steam-Gauge Company, Boston, Mass., who have been emine successful in the manufacturing of first-class instruments for m years. The original designs of Mr. Thompson have been so what modified and improved by the American Steam-Ga Company, as will be observed from a comparison of the cut page 495 with those on page 501, the former representing indicator as originally constructed and the latter the "Thom Improved Indicator" as it is called by the American St Gauge Co.

The important improvements consist in lightening the mo parts, substituting steel screws in place of taper-pins, using a light steel link instead of a large brass one, reducing the we of the pencil-lever, also weight of square in trunk of piston lock-nut on end of spindle, and increasing the bearing on con tion of parallel motion. By shortening the length and redu the actual weight of the paper cylinder just one-half, and by sl ening the bearing on spindle so that it now carries the drum-sp nearer the base, they have reduced the momentum of the p cylinder to a very small amount. All of these improvements lessened the amount of friction, which was heretofore very s but is now reduced to a minimum, and the Thompson Impr Indicator as it is now made is a very excellent instrument.

Tabor's Indicator.

The cuts on pages 503, 504, represent Tabor's Steam-En Indicator.—As will be observed, its most striking features ar parallel motion and the plainness of its cylinder. The piston a single capillary packing groove, and its whole action is rem ably nice. The springs, both as to range and general struct are similar to those in the Richards and Thompson Indicator. will be noticed that the piston-rod, which is jointed to the pi and the pencil-lever, is slotted; this slot is curved, and w over a guide-roller set in the cylinder-cap. The rear end of

er is pivoted to the radius link. The slot-curve is that
urve which would be described by the guide-roller as a
oint while the pencil is being moved in a true line;
claimed, insures a correct parallel motion to the pencil.
-roller is journalled in a free collar held in the cylinder-
ch allows
ving parts
freely, as
is brought
t with the

per drum
on a steel
pon which
m nut is
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e drum is
illed head
rewed on
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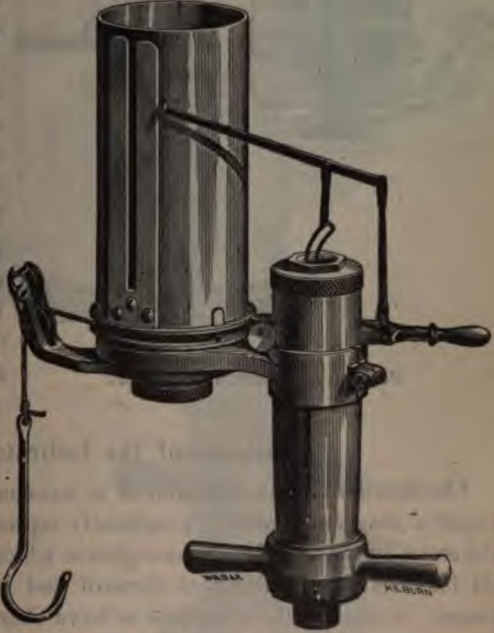
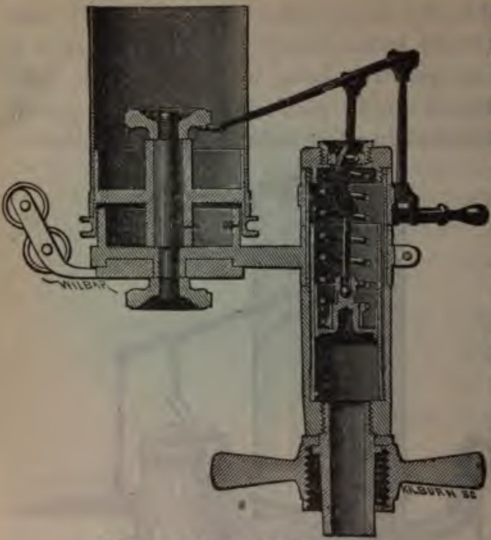
The recoil-
eated in a
e bracket,
end being
, while the
is hooked
ub on the
e. A stop-
the cup, engaging with a lug in the drum-base, forms the
he recoil motion. If the spindle be slacked somewhat,
-base may be revolved over the stop-block, and more or
n given to the recoil-spring. By simply unscrewing the
ap, the whole motion work may be removed in one
e *pencil-lever, piston-rod,* and radius-link, are all of steel,



Tabor's Indicator.



Section of Tabor's Indicator.

spring tempere
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instrument is
light, the desig
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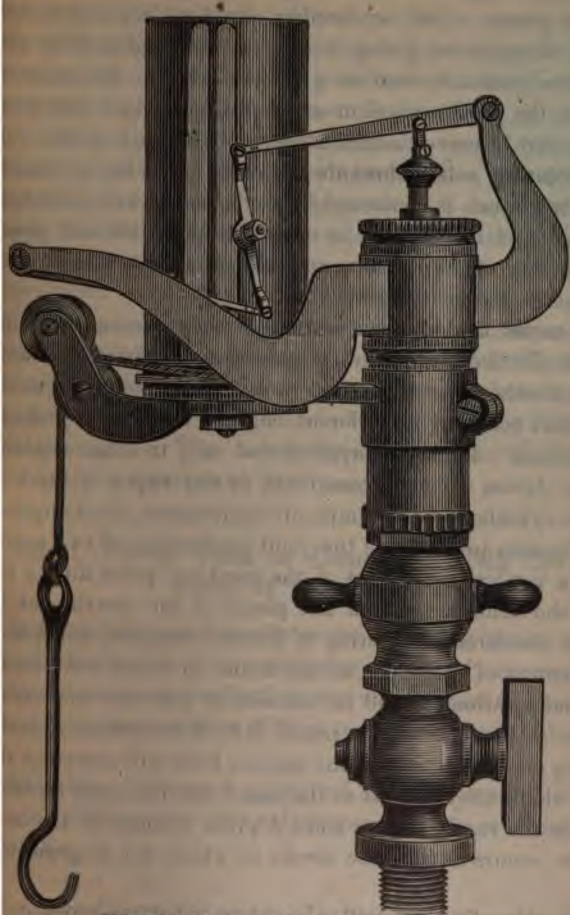
manship neatl
It is claimed t
diagrams pr
are very good.

Functions of the Indicator.

The function of the indicator is to automatically trace
paper a diagram that will graphically represent the press
the steam in the cylinder of the engine to which it is attache
all its variations during both forward and return strokes
piston. It enables those who use or have charge of steam-e
to ascertain the condition of the parts of the engine subj
the direct action of the steam, and to what advantage the
is applied; whether the valves are properly designed a
curately set, and if the steam-passages or ports are of the
size to receive and discharge the steam in time to produce th
effect; what pressure of steam there is upon the piston at
position in the cylinder, as well as its average during the s
[illegible] the value of the vacuum acting upon the piston of
gine in all its positions in the cylinder, and wha



Richards' Parallel Motion Indicator.

average; whether the exhaust passages from the cylinder are sufficiently large to give free exit to the steam, and, if not, what percentage of power is lost in forcibly expelling it; the actual consumption of steam in giving motion to the engine, and also what additional steam is used in giving motion to the shafting and millwark, the paddle-wheel or screw-propeller; and also what power is required to move the machinery, or any part of it.

In manufacturing establishments where power is let to tenants it will show how much is consumed by each, and it will also demonstrate the degree of economy in using steam at different pressures, the benefits of expansion, and the relative efficiency of different kinds of expansion-gear.

Indicator cards are of great value, as they demonstrate the initial, mean effective, and terminal pressures, the back pressure, the cushion, whether by compression or lead; the point of cut-off, and the relative economy of different engines, aside from leakage and condensation. It may be applied not only to steam-engines, but to those driven by compressed air, or any vapor or fluid, as well as to the cylinders of air-pumps, air-compressors, blast-engines, etc. The diagram produced is the joint production of two movements, viz., a vertical movement of the marking point due to the pressure of the steam acting on the piston of the instrument, in opposition to the force of a spring of known strength, and a horizontal movement of the paper, as the drum, on which it is placed, makes partial rotations to and fro coincident with the movement of the piston. Hence, when the pencil is held in contact with the paper during one revolution of the engine, both will arrive at the point from which they started at the same moment, and a closed figure will be the result, except when a great change in the load and pressure occurs during the stroke in which the diagram was taken.

The indicator diagram will also show what proportion of the boiler pressure is contained in the cylinder; how early in
'e *the* highest pressure is reached; how well it is main-
; *what* point and at what pressure the steam is cut off;

ther it is cut off sharply, or in what degree it is wire-drawn;
hat point, and at what pressure it is released; whether it is
ly discharged, or what proportion of it (in excess of the atmos-
e or the vacuum in the condenser, according as the engine is
lensing or non-condensing) remains to exert a counter or back
sure; whether, before the commencement of the stroke, there
y compression of the vapor remaining in the cylinder, and if
t what point in the stroke it commences, and to how high a
sure it rises. The foregoing particulars can only be learned
bservation, though a scale, corresponding with the spring used,
eded to measure the pressures, and to locate the exact events
e stroke. The points to be calculated in estimating diagrams
the mean or average pressure; the total mean, or the mean
tive pressure; the indicated horse-power, I. H. P., and the
retical water consumption. The indicator shows the pressure
ch and every point in the stroke; to represent this faithfully
s sole office. The causes which determine the form of the
e must be determined by the engineer.

hnical Terms Used in Connection with the Employment of the Indicator.

he term Adiabatic literally means no transmission. As applied
n expansion curve, it means that it correctly represents at all
ts the pressure due both to the volume and the temperature,
as if no transmission of heat to or from it had taken place.

dmission.—This term is applied to the induction of the steam
the cylinder when the valve opens at the commencement of
stroke.

he term Asymptote means a line which approaches nearer and
er to some curve, but which, though infinitely extended, would
r meet it. The *clearance and vacuum lines of a diagram are*
ptotes of a true expansion curve.

The letter B at the end of a diagram means that that end taken from the bottom end of the cylinder.

A. B. or Aba. is understood to stand for above atmosphere, B. A. or Bla. below atmosphere.

The term Compression is a term used to express the dist through which the piston moves in the cylinder after the exl has closed. Compression takes place between the piston an cylinder-head at the end of each stroke; and the distance fron end of the cylinder at which it takes place depends on the an of lap on the valve.

The term Cushion means the resistance offered on the op side of the piston induced by the steam shut up in the cylin

Cylinder efficiency.—This term is used to designate the an of work performed in the cylinder of a steam-engine for a pressure.

The term Clearance is used to express the extent of the which exists between the piston, the cylinder-head, and the v face at each end of the stroke. See page 363.

Displacement. — This term is applied to the cubic conten the volume of water, steam, or air displaced by the piston d one stroke. It may be found by multiplying the area of the in inches by its stroke in inches. The product will be its dis ment in cubic inches.

Duty. — This term is understood by engineers to mean th ciency of steam-engines, or the number of pounds that an e is capable of raising one foot high per second with an expen or consumption of one hundred pounds of coal.

The term Flexure means bending or curving. The poi *flexure in a diagram* is the point at which the cut-off closes *the expansion* curve begins, as shown at C, explanatory di

1, page 537. The point of contrary flexure is the point at ich the line changes its direction by curving outwards and erwards inwards, as shown at A, on diagram on page 537.

H. P. cyl. stands for high-pressure cylinder.

H. P. means horse-power, which, when applied to the steam-gine, means 33,000 lbs. raised one foot high; or 150 lbs. raised 0 feet high; or 550 lbs. raised one foot high in one second.

The term Hyperbola means a plane figure which is formed by tting a portion from a cone by a plane, parallel to its axis or to y plane within the cone, which passes through the cone's vertex. e curve of the hyperbola is such, that the difference between distances of any point in it from two given points is always ıal to a given right line.

The term Isothermal means uniform or same temperature. As plied to an expansion curve, it means that such a curve repre-its correctly the expansion or compression of the steam when temperature is uniform.

L. P. cyl. means low-pressure cylinder.

The term Ordinates means the vertical lines drawn across dia-ıms to facilitate the calculation of their power. See diagram page 537.

The term Parallelism is generally employed, where two or more aight lines may be extended indefinitely, without any tendency approach or diverge from one another. See atmospheric and cuum lines on indicator diagrams.

Release. — This term is understood to mean exhaust. *Resid-y* exhaust is that which follows the first release of the terminal ssure. The term *negative exhaust* is sometimes used, though generally understood in its literal sense. It means compres-*or cushion, and absolutely* amounts to the same thing, as it is merely an early product of the exhaust, for the purpose of reta ing a portion of steam in the cylinder as the crank approac the centre of the stroke.

Rev. or Rev's is understood to mean revolutions per min though *rspm* is sometimes used.

I. H. P. means indicated horse-power. It means the nun of H. P. of energy shown by the diagram of an engine, as fo by multiplying together the area of the piston in square in its speed in feet per minute, and the mean effective pressure sh and dividing the product by 33,000.

N. H. P. means net horse-power, which is the I. H. P. m the friction of the engine.

The term Initial pressure is generally understood to mean pressure represented in the cylinder between the opening of steam-valve and the closing of the cut-off. More properly sp ing, it is the pressure represented in the cylinder at the comm ment of the stroke, as the pressure frequently falls consider before the closing of the cut-off.

M. E. P. means mean effective pressure. It is simply amount by which the average impelling pressure exceeds average resisting or counter-pressure. The M. E. P. on the pi of a steam-engine is the measure or exponent of the work formed.

The term Terminal pressure means the pressure at which steam is exhausted from the cylinder, and may be said to be exponent of the consumption of water by the engine.

The term Pipe diagram is applied to diagrams taken from steam-pipe for the purpose of determining how much of the pr ure of the steam in the pipe is lost in passing through the ste ports to the cylinder.

The term Scale means the number of pounds of steam per square inch (acting on the piston of an engine) represented by each inch of vertical height on the diagram. Thus a 40 lb. scale means that each inch on the diagram represents 40 lbs. of steam per square inch, and so on.

The term Spring means the spring which is employed on the piston of the instrument, in order to resist the pressure of the team and the vacuum. The following **table** will give the limit f pressure in the cylinder to which each spring may be subjected. The length of each spring given in the third column is such that each of them would be extended (when subjected to a perfect acuum) to a length of $2\frac{7}{16}$ inches, which is the approximate ength which would carry the pencil to the lower limit of the range of movement above given.

Scale of Spring.	Limit of Cylinder-Pressure above Atmosphere.	Length of Spring.
15 lbs. per in.	25 lbs.	2·192 ins. = nearly $2\frac{1}{5}$ ins.
20 " "	38 "	2·255 " = a little above $2\frac{1}{4}$ "
30 " "	64 "	2·315 " = " " $2\frac{3}{10}$ " or nearer $2\frac{5}{16}$ "
40 " "	90 "	2·345 " = nearly $2\frac{7}{20}$ "
60 " "	143 "	2·376 " = a little over $2\frac{3}{8}$ "
80 " "	195 "	2·391 " = a little above $2\frac{2}{5}$ "

To find the corresponding limit for grades not given, *multiply* he total range of movement, 2·625 inches, by the scale of the pring, and deduct the pressure of the atmosphere.

Example.—Suppose it is desired to find the limit of pressure for 50 lb. spring: 50 × 2·625 — 14·7 = 116·55.

The term String, *as used in* these pages, means the aggregate *gth of the ordinates of an* indicator diagram.

The letter T on a diagram denotes that that end was taken from the top end of a cylinder.

The term Undulating means rising and falling, wavy. See dotted line on diagram No. 16, page 549.

Wire-drawing.—This term is applied to the common method of regulating the flow of steam from the boiler to the cylinder by throttling or forcing the steam to ooze through some small o intricate device, such as the governor-valve, thus tending to destroy its elastic force.

The term Zero, when applied to indicator diagrams, means vacuum.

How to Attach the Indicator.

Since it is of the first importance that the diagram should b correct, both as to its vertical and horizontal measurements, to much care cannot be taken in making the attachments. The bes method of attaching the indicator to the engine is to drill and tap into the cylinder directly opposite the ports. When practicable, the holes should be located exactly at the centre of the clearance, or the space between the piston and the cylinder, whe the crank is at the dead-centre; since, if the holes are bored in any part of the cylinder which is travelled over by the piston, the communication with the indicator will be closed at that point i each stroke. Care must also be taken that they are not too clo to the cylinder-heads, as the projecting parts of the latter may interfere with the free flow of the steam between the cylinder and the indicator. But if such a difficulty should arise, recesses must be cut in the cylinder-heads, in order to establish the communication. If the heads can be removed for the purpose of locating the holes, it is always best to do so, as their exact location can be determined with perfect accuracy.

If circumstances will not admit of the holes being drilled into *the clearance,* they may be put in the heads; and, if it is not in

d to place the instrument in connection with both ends of
ylinder at the same time, this location is preferable. It is
ed by many engineers that reliable diagrams cannot be ob-
l, when the pressure has to be transmitted through a long
as is the case when the instrument is connected to both ends
e cylinder. But it has been shown by experiment, that if
ylinder is tapped instead of the heads, thereby using the
est pipe, and the stop-cocks are placed as near as possible to
nstrument, the difference between diagrams so taken, and
taken from a direct attachment, is not always noticeable.
stead of two stop-cocks, one on each side of the instrument, a
way cock be placed under it, which will allow steam to be
tted from either end through the same plug, the difference
ardly be detected. If no such cock can be had, straight way-
of ample aperture, placed as close to the *L* or *T*, to which
nstrument is attached, as possible, will give sufficiently satis-
ry results for all ordinary purposes. When, however, it is
ed to take the diagrams separately, two cocks become neces-
and the card must also have two loops or hooks, as far apart
e two positions which the instrument is to occupy. Then it
be quickly shifted from end to end as desired. If two in-
ents are attached to an engine, diagrams may be taken
taneously from both ends; but, while such an arrangement
tes the difficulty of equalizing the events of the two ends
one instrument, it is open to the objection that, if there is any
ence in the action of the two instruments, or in the strength
eir springs, this circumstance will interfere with the com-
on.

Motion of the Paper Drum.

ing to the almost endless variety of engines, their peculi-
s of design, etc., it is impossible to give very definite instruc-
which will be applicable to all cases. But it must be borne
nd, that the *motion of the* paper drum must be coincident
that of the piston in respect to its times of stopping and

starting, and be a miniature reproduction of it in all othe spects; or, in other words, equal piston movements must be resented by equal movements of the paper throughout the stroke. To whatever the cord may be attached, whether to a porary wooden pendulum fastened by a screw to a post, or t beam of a beam-engine, it (the cord) must be at right angle line between its point of attachment and the pivot of the bea pendulum to which it is attached, when the piston is in the m of its stroke. For instance, suppose the engine to be horiz and that a wooden pendulum is attached to a light post set or on the engine, or some other convenient object, or is susp from a joist, the lower end being connected to the cross-head that the point on the pendulum where the motion is suffici reduced for the paper drum is higher than the instrument, s the cord must incline downward. In such a case, unless a ing pulley is used to deflect it to a horizontal direction, or the point of attachment for the cord is moved as many d from the centre line of the pendulum as the cord inclines wards, the movement of the pendulum will be too fast at on of its travel, and too slow at the other, and the diagram w distorted. The effects of such distortion will be to cause th to appear unequal when they are not so, or else to conceal aggerate inequalities where they really exist.

The length of the pendulum may be from one and a half to twice the length of the stroke or more. If too short, the of the diagram will be distorted, unless the connection betw and the cross-head is sufficiently long. The pendulum m attached to some object at the side of the engine, so that it vibrate in a horizontal plane.

A good substitute for a pendulum consists of a drum abo inches in diameter, more or less, on the axis of which is a drum, the diameter of which requires to be as much less tha other as the movement of the paper is less than the travel *piston.* If the drum is mounted in a convenient position, the large part is attached to the cross-head, and e small part to the indicator, a spring in the large drum ts cord taut, just as the spring in the drum of the in- keeps its cord taut.

n two instruments (right and left), are used, it is best to iding-bar alongside of them having the proper motion, g pins to which the cords are attached, these pins being between the two instruments so that the cord of each may wards the other, and the movement of the piston from nd of the cylinder may pull the cord of the instrument l to that end, in which case the upper line of each diagram ill be drawn while the cord is being pulled. But no per- advantage in the way of accuracy need be expected from angement, though it is a very convenient one where a large of diagrams are to be taken.

Analysis of Diagrams.

defects in engines as revealed by the indicator diagram st clearly understood by comparing the diagram of the in question with a theoretically perfect diagram—that is, ch would be obtained from an engine in which both the and the adjustments were perfect in every way. Let us, e, begin the consideration of the indicator card and its th the analysis of such an ideal diagram.

agram No. 1, *A A* shows the atmospheric line which is when both sides of the piston of the indicator are exposed mosphere. When tracing such a diagram it is preferable he cord by hand, in order to make the atmospheric line han the diagram; *B C* is called the steam line. It is while steam is entering the cylinder. *C* is the point of It cannot always be located exactly by inspection, as the of the part is generally sufficiently gradual to cause con- e fall of pressure before the port is entirely closed. In it *may be located at* the point where the outline of the *ases to be convex* and commences to be concave. C D

is the expansion line or curve. *D* is the point of exhaust, whi
like that of the cut-off, may be located at the point *of cont*
flexure, or that point where the expansion line begins to cha
the direction of its curvature. *D E* is the exhaust line. It c
mences at the point of exhaust, and may be considered as
minating at the end of the stroke, (though, strictly speakin
does not terminate till the exhaust port closes at *F.*) *E*
termed the counter- or back-pressure line, and by some the
uum or exhaust line; but the former terms are more appr
ate, as they are applicable to all diagrams, whether from con
ing or non-condensing engines. In the diagrams of non
densing engines it is above the atmospheric line, *A A*;
in condensing engines it is below; but in both cases it
resents some counter-pressure, since a perfect vacuum is
tainable. *F* is the point of exhaust-closure. Its exact
tion cannot be so readily determined as the points *C* an
as, although like the former, it is anticipated somewhat
change of pressure, it is not marked by any change in the
tion of the curvature of the line. In perfectly working en
it may be located geometrically, but it is seldom necessary
so, since for all practical purposes it is sufficient to know
the change of pressure due to the closing of the exhaust b
and its final result. *F G* is the compression curve, and *G*
the admission line. These constitute all the lines which b
to the diagram proper, and all that are produced by the in
ment.

For certain purposes the vacuum line *V V,* and the clea
line *H H,* diagram No. 1, are drawn, the former parallel t
atmospheric line, and at such a distance below it as will
sent, according to the scale used, the pressure of the atmos
as it was, or was supposed to be, at the time and place at
the diagram was taken. For this purpose it is usual, when
accuracy is desired, to consult a barometer at the time
record its reading on the card; but, in the absence of a b
ual to assume the pressure at 14.7 lbs. per

which is the average at sea level; but, since the pressure
ishes at the rate of $\frac{1}{10}$ lb. for each 189 feet of elevation,
ance should be made for the known or estimated eleva-
of the locality. It should also be remembered that the
ure will vary nearly ½ lb., and sometimes more, from changes
e weather.

e clearance line *H H*, diagram No. 1, is drawn perpendicular
e atmospheric and vacuum lines, and at such a distance from
nduction end of the diagram, that the space between them
bear the same proportion to the whole length of the latter
e whole volume of clearance bears to the piston displace-
. When the amount of clearance is unknown, and it is not
icable either to calculate it or measure it by filling the space
water, it must be approximated as near as possible from the
n clearance of engines of similar construction. The largest
ance will be generally found in the smaller sized engines of
rdinary single slide-valve type. Five such engines tested at
incinnati Industrial Exposition of 1875, had the following
nts 9, 9½, 10, 11⅘, and 12 per cent. of the cubic contents of
ylinder. Next to these will be the larger sizes of the same
in which the clearance will range from 6 to 10 per cent.
n two slide-valves are used with short, direct ports, but ex-
ting under the valves, the clearance will average from 3 to 6
ent., according to the proportionate length of the stroke, the
est strokes having the smallest per cent. Corliss engines, in
h the stroke is about three times the bore, have about 3 per
The least amount of clearance is obtained from valves de-
d to exhaust at both ends of the cylinder, instead of in the
re, as in the case of the ordinary single slide-valve. By such
rrangement of the steam- and exhaust-valves, the clearance
n many instances been reduced to 1¼ per cent. The clearance
ppet-valve engines is more difficult to calculate than in slide-
e engines; but, as a general thing, it does not exceed 5 per cent.
ould be measured *with water*, when it is desirable to ascertain
rately the cubic contents of the clearance. In poppet-valve

engines the cut-off and other events are independent and adjustable; consequently, diagrams taken from this class of engines are free from the limitations attending those taken from slide-valves, because advantage is frequently taken of their freedom of adjustment to give an earlier cut-off, or a later depression than is usually adopted with slide-valve engines. In all such cases the diagram will faithfully state the fact.

Diagrams taken from Throttling Engines.

The conditions which are mainly instrumental in determining the conformation of the diagram are the valves and valve-gear, the length and capacity of the steam- and exhaust-pipes and ports, the design of the governor-valve, the condition of the valves and piston as to leakage, the amount of clearance, the speed of the piston, etc. The engineer may be called upon to analyze a diagram with reference to all the above conditions, or only to accidental derangements. In the first place, he must compare the diagram with one of the best form which can be produced in practice from the class of engines to which the one in question belongs; in the second case, he must discriminate between such defects as are due to accidental derangements and those that are due to design and construction, which cannot be remedied without the substitution of new parts. Suppose the engine to be of the throttling kind, of the best attainable construction and adjustment, its diagram should possess the following general features:

1. **The initial** pressure at *B*, diagram No. 1, should be as high at least as any subsequent pressure; and if the engine is not driving its maximum load, and the steam is in consequence more or less throttled, the pressure should begin to fall at *B*, and continue to do so at a tolerably uniform rate, until the point of cut-off, *C*, is reached.

2. ***The cut-off***, when obtained by means of lap in the slide-valve, cannot, as a general rule, take place with advantage earlier

ıe stroke than about $\frac{5}{8}$, as the angular advance necessary to any earlier cut-off would involve a too early exhaust and com- ion.

From the cut-off, *C*, to the release, *D*, is the expansion :. Assuming the applicability of the Mariotte law to expand- team, the shape of the expansion curve, *C E*, should be such if the distance from any point in it to the clearance line, *H* ken on a line parallel with the atmospheric line, be *multiplied* ıe distance from the same point to the vacuum line measured ;ally, the product will be the same for all points in the curve. ;e, if at the commencement of the curve, the two measure- s are multiplied together, and the product divided by the ıce from the clearance line to any other point, the quotient be the distance of that point from the vacuum line, or the ure at that point, if the pressure scale is used for the measure- s.

The release at *D* will take place earlier or later, according to ımount of lap, both steam and exhaust, that is introduced. steam-lap affects it indirectly, as, the greater it is, the greater ngular advance necessary to maintain the proper lead. Lap e exhaust side affects it directly without change in the angu- dvance, by opening the port so much later, and consequently ıg it so much earlier. The requirements of perfect working hat it shall be early enough to release the piston of all undue pressure before much of the return stroke is made, and late gh not to materially diminish the power of the engine. The ırmation of diagram No. 1, page 537, shows about as early xhaust as is admissible, because little or nothing would be ;d by a later one, as the steam is not thoroughly exhausted the piston has moved a short distance on its return stroke; while a later release would add a little to the average forward ure, it would also increase the back pressure. Besides, a later se would involve either a later cut-off or an earlier compres- and, although *the general* practice is to place all these events *than is shown on the* diagram, such practice is not calculated to realize the best possible steam economy with that class gines.

5. **The back-pressure line,** *E F*, should coincide with the phere, or nearly so, in non-condensing engines and wi pressure shown by the vacuum-gauge in condensing e When it is in excess in either case, it indicates insufficient ity in the exhaust-ports or pipes, or both.

6. **The compression curve,** *F G*, owes its form to the sa that govern the expansion curve, and its degree of confor theory may be tested by the same methods. The only difi between the two are in the quantities of steam evolved production, and the order of their formation; the ending corresponding to the beginning of the other. As to the required to satisfy the best conditions, some difference of exists. It is ascertained that a certain amount is advant as a means of arresting the momentum of the reciprocatin while changing the direction of the force on the crank-| more gentle and quiet manner, than would be done by the sion of steam as an opposing force. If the compression, c properly speaking, the cushion has fulfilled its functions. duction will find the parts already prepared for the sho prevent a jar or thump. The maximum pressure reachec cushion should never be greater than the average initial p but within this limit considerable latitude exists, as, while i ishes the power of the engine, it lessens the consumption o The less the exhaust-lap, the earlier the exhaust will tak and the later the compression, and *vice versâ.*

7. **The lead line,** *G B*, need not conform to any a standard. It satisfies the eye of the engineer best when i tical, or nearly so; but it may lean slightly inwards, in deficiency of lead, or outwards, indicating excess, without a the economy of the engine, and in most cases without affecting the smoothness of its running. In many cases t *me*[illegible]*ent* of the lead line proper cannot be exactly locat

ys run best when the compression and lead ı other with an easy curve. When a single slide-valve is used, ı the steam- and exhaust-lap must be provided for in its con- ction, and cannot be subsequently changed without a change ıroportion. But since it is not the absolute amount of lap, but ımount relatively to the travel of the valve, which determines nfluence, it follows that, by reducing the travel, the lap both m and exhaust will be virtually increased, and *vice versâ.* r change of travel must be accompanied by such change of ılar advance as will maintain the proper lead. The adjust- t of the cut-off by the link-motion of the locomotive is an ınce of such change of travel and angular advance.

ı **the foregoing description** all the capital letters refer to dia- n No. 1, on page 537.

Vhen two slide-valves are used, each performing the functions ıduction and exhaust at its own end of the cylinder, the steam- may be increased by setting them farther apart, and dimin- d by contracting their connection; but in such cases steam-lap btained at the expense of the exhaust-lap, and *vice versâ.* ring learned from an engine embodying correct construction performance the general features which should characterize ıagram, the *engineer* will have no difficulty in recognizing cts as well as deviations from diagram No. 1, on page 537. se conditions should be understood before the slide-valve, ıttling engine diagram can be intelligently criticised.

Diagrams taken from Automatic Cut-Off Engines.

'he points of difference between diagrams from automatic off engines and those from slide-valve engines will be mainly ıd in the steam lines, the points of cut-off, and the expansion re. When the automatic cut-off engine is worked in accord- ; with the theory of its operation, the steam is never throttled ;he purpose of regulating the speed, but is admitted freely to valves, *the speed being regulated solely by means of variations e point of cut-off.* Hence, the steam line should indicate a pressure equal to that in the boiler, whatever the load may be, and would undoubtedly do so, if the proportions were good and the valve-gear in perfect order. The necessary difference, then, between the throttling and automatic cut-off engine diagrams, may be thus stated. In the former, the height of the steam line varies with the load, the length remaining the same; in the latter, the length of the steam line varies with the load and pressure, the height remaining always approximately that of the boiler pressure.

The theoretical diagram.—From what has been said in the foregoing paragraphs, it is clear that a theoretical diagram may be constructed, representing perfect performance on the automatic cut-off principle, which cannot be done in the other case, as the height and conformation of the steam line depends on conditions too numerous and complex for analysis. Thus, with a given boiler-pressure for a steam line, a straight horizontal line may be drawn, corresponding with that pressure, and, from a given point of cut-off, an expansion curve may be drawn having the properties already described, and reaching to the end of the stroke. If the remaining terminal pressure is greater or less than the counter-pressure, a vertical line extending upwards or downwards to the height required by the counter-pressure will represent a perfect exhaust line. Then, for the return stroke, a line coincident with the atmosphere or a perfect vacuum, according as the engine is non-condensing or condensing, will represent the counter-pressure, and a vertical line up to the beginning of the steam line will represent the admission line and complete the figure.

If a compression curve is desired, it may be drawn through the assumed or actual point of exhaust-closure on the counter-pressure line, but such a curve cannot originate from a perfect vacuum. Hence, when the diagram is from a condensing engine, and the actual compression curve is to be tested by a theoretical one, the latter must be based on the actual counter-pressure present at the closure of the port.

***This theoretical* diagram** being for the present assumed to erfect, not in the sense of representing the best conditions in an conomical point of view, but only the most perfect performance ossible under given conditions, is nevertheless the standard with hich the actual one is to be compared, and by which it is to be udged. For this purpose it is customary to draw it around the ctual, so that the imperfections of the latter may be readily seen nd their magnitude estimated.

Application of the Theoretic Curve.

On tracing the theoretic curve on diagrams from different ngines, a great difference in the degree of theoretical correctness hown in their expansion curves is revealed. The deviation from e theoretical is always in the direction of a higher terminal ressure, unless it is caused by excessive piston leakage. This ay be explained on two suppositions, viz., leakage of the cut-ff valves, and evaporation of the spray or water of supersatration in the steam during expansion as the pressure decreases. ill recently the former was the only explanation offered, but, in ore modern times, the latter has almost entirely displaced it. here is no doubt that both causes are in some degree responsible r the phenomenon, but the diagram itself seldom furnishes any liable indications pointing to either cause to the exclusion of the her; nor does a study of the conditions under which the greatest correctness shows itself throw much light on the subject. As a eneral rule, large engines give more correct expansion curves than nall ones, though numerous exceptions are met with in both ses.

Incorrectness is generally less with heavy loads than with light nes. But both the foregoing facts can be explained on either eory, since, with equal care in the fitting of the valves, a large gine will leak less in proportion to the amount of steam used an a small one. But the evaporation of the spray will be less erfect in the former than in the latter, owing to the longer time *cupied in effecting a given* degree of expansion, during which the heat of the water, instead of being effective for evaporation, will be dissipated. In small, fast-running engines the steam undergoes a more rapid expansion, and the heat, rendered sensible by the removal of the pressure, has less time to be taken up by the cylinder walls, and is consequently more effective in vaporizing the moisture. Another fault in small engines is imperfection in the cut-off valves. Both causes afford better facilities to operate with an early than with a late cut-off, the longer time afforded by the former, and the less pressure under the valve, being favorable to the greatest leakage; and the greater the change of pressure is, the more favorable it will be to the evaporation of the moisture.

If, however, the deviation should (other things being equal) be found to be greatest when the water is high in the boilers, or when the steam is being rapidly generated, that fact would point to the spray theory as the undoubted cause of part of it. Such appears to be the case to some extent, though the observations taken on that point have not been numerous and careful enough to be of much value. But, whatever may be the cause of the phenomenon, it is so general that, whenever a very correct curve is met with, the suspicion of piston or other leakage, the tendency of which is to lower the pressure during expansion is always justly raised, and should be disposed of by test or otherwise, before such a curve can be confidently accepted as evidence of correct performance. Nevertheless, very correct curves are sometimes met with when piston leakage does not exist.

The most obvious lesson to be deduced from the facts at present in our possession, seems to be that, when any considerable incorrectness is met with in the curves of the diagrams taken from large engines, a considerable amount of leakage may be confidently inferred. But, in the case of small engines, particularly fast-running ones, the amount of incorrectness which may be caused by re-evaporation is undoubtedly greater than in large ones; but even in them the cut-off valves should not be too readily excused without examination.

The Initial Pressure, or Steam-Line.

close approximation of the steam-line of an automatic cut- liagram to the boiler pressure is rightly regarded as an indi-)n of good construction and performance. Other things being l, that engine which most nearly obtains the highest boiler sure on its piston at the commencement of the stroke, may)ff the earliest — attain the highest ratio of expansion — and ust the steam at the lowest pressure. The last condition is the)f all improvements designed to promote steam economy, as, if do not produce a lower terminal pressure for the same work, do not fulfil the conditions for which they were intended. It)t sufficient to rely on the steam-gauge as a test of the steam- unless it has been recently tested and found correct. Most n-gauges deteriorate by use, especially if exposed to undue or cold. When practicable, the engine should be stopped blocked, or placed on the centre, steam admitted to the indi- r at full pressure, and a line traced by hand. If this has been ;, and a difference of four or five pounds between boiler and al pressure be detected, how is the difference to be accounted The pipe may be too small, long, or crooked, or the ports nadequate; or both these defects may exist. To test this er, a connection should be made between the indicator and steam-pipe above or below the throttle, as may be thought erable. By means of this connection, a diagram representing luctuations of pressure in the pipe is produced over the engine ram. A diagram produced in this way will show whether loss of pressure is due to the ports or the pipe. In such a , the pressure falls, when it is admitted to the cylinder, until it eds the initial pressure but little more than one pound. Then, on after the steam is cut off, as the space immediately above cut-off valve can fill, the pressure rises, and the momentum he steam in the pipe evidently carries it above that of the er, and *about the middle of* the stroke it falls again, evidently r *below the boiler* pressure. At about three-fourths of th stroke it rises again, but this time not so high as it did at its first rise, probably not above boiler pressure. These secondary fluctuations possess no special significance, except as showing that the boiler pressure is to be determined by finding the mean of their extremes. Their frequency during the stroke will depend on the length of the pipe as determining their frequency in time, and on the speed of the engine as determining their relative frequency. The pressure of the steam also affects them, as high-pressure steam is denser than low. The trouble involved in making the necessary connection for such a diagram will of course exclude them in most cases, but their value to the engineer, as a means of arriving at correct proportions for the pipes and ports, will be apparent.

The Mean Effective Pressure.

Whatever uncertainty may attach to the inferences deduced from indicator diagrams, there is every reason to believe that, provided that the spring is correct, the instrument in good working order, and its indications mathematically calculated, the conclusions will be reliable. The usual method of calculating the mean effective pressure is to divide the diagram into any suitable number of equal spaces by lines or *ordinates,* to measure the centre of each space with the proper scale, and to take the average of the several pressures by dividing their sum by their number. But since it is easier to measure on a line than to guess at the centre between two lines, it will be preferable to make the first and last spaces half the width of the rest, which will make the lines stand in the centres of equal spaces. The measurements are then taken on them. Diagram No. 1, page 537, is lined in this manner. The most expeditious and accurate method of obtaining the average of these ordinates is to take a slip of paper, apply its edge to each of them in succession, and mark their combined length on it. This length in inches multiplied by the scale of the *spring used,* and the product divided by the number of ordinates *measured,* will give the desired average. By using a sharp-pointed trument, as the point of a knife, thrusting it into the paper at foot of each ordinate, moving it to the top of the next, and rying the strip with it, the measurement may be taken with at ease and rapidity.

he simplest method is to measure the ordinates between the ct and counter-pressure lines. This will give results accurate ugh for most purposes; in fact, it will give the mean average he two ends with entire accuracy, and this must always be ob- ed as a basis for calculating the power of the engine. But, e a diagram, from either end of the cylinder, represents, by its er line, the pressure which impels the piston during one stroke, by its lower, the counter-pressure which opposes it during the ke in the opposite direction, it follows that, from either diagram e, a corrrect balance for either of the two strokes which it esents cannot be struck. To do this, the mean counter-pressure he one must be deducted from the mean impelling pressure of the r. To obtain these pressures separately, it is necessary to draw measure the ordinates from the lines representing them to the uum line. This, however, is unnecessary, except for very ac- te analysis. In general, the counter-pressure of the two strokes be very nearly equal, especially if the exhaust and cushion properly equalized; and even where they are unequal, the final rage of the two ends will be correct.

he number of ordinates may preferably be one-fourth, one- d, one-half, or equal to the number representing the scale used; hich case it will only be necessary to multiply the combined th of the ordinates (or the *string*, as it may be called) by 4, r 2, as the case may be, to obtain the desired result. If the ber is equal to the scale, the multiplier, being 1, need not be l. Thus, suppose the scale to be 40, the number of ordinates and the string 14½ inches. As the scale represents twice the ber of ordinates, the string being multiplied by 2 will give a luct of 29 lbs. mean pressure. Or suppose diagrams to be n from both *ends of the cylinder*, either on the same paper or *rately, and the one to* be calculated and averaged with the other. The string of both may be taken together on the sa strip, and if the scale is twice the number of ordinates, the leng of the string will give the mean pressure at once without mul plying. When taking such a continuous string for two diagra the termination of the first should be marked with a pencil, that the two may be compared.

When diagrams are met with, in which the expansion cu crosses the counter-pressure line, the string should be taken f the beginning up to the point where the lines cross, and after in a reverse direction on the strip, so as to cancel the part of string already made. When the terminal end is reached, remains of the string first made will give the mean effective p ure (M. E. P.) in the usual way; or the total mean impelling counter-pressure above vacuum may be found separately, and difference ascertained.

To Space the Ordinates.

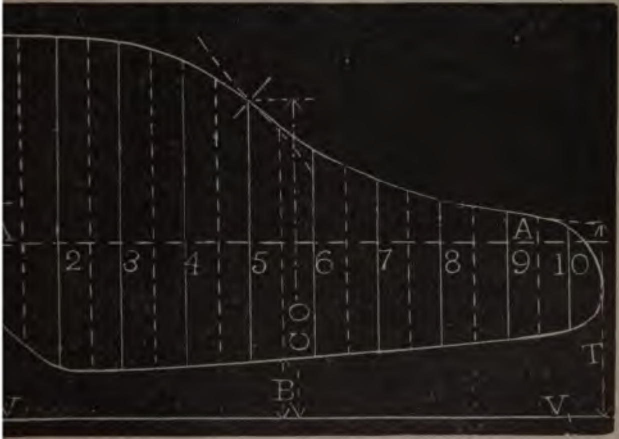
Draw vertical lines touching the ends of diagram No. 1, *E I*, and apply a rule across them in a more or less oblique d tion, till some division on the rule, as $\frac{1}{16}$, $\frac{1}{12}$, $\frac{1}{10}$, $\frac{1}{8}$, or $\frac{1}{4}$, will di the distance between the points where the rule crosses the an even multiple of the number of ordinates desired. the dotted oblique line in diagram No. 1 is $3\frac{3}{4}$ inches long, contains the $\frac{1}{16}$ division 60 times; consequently, $\frac{3}{32}$ pointed o each end, and $\frac{3}{16}$ for the other spaces, will correctly divide diagram for 20 ordinates. With a little greater obliquity the tance would be 4 inches, when $\frac{1}{10}$ inches would be right for end spaces, and $\frac{2}{10}$ for the rest.

To Calculate the Indicated Horse-Power (I. H. P.).

Multiply the speed of the piston in feet per minute by the a of the piston in square inches, and divide the product by 33,0 ult will be the H. P. for each pound of M. E. P.

alue of each pound. See table on page 566. Then multiply E. P. by this value. This method is preferable to multi- by the M. E. P. before dividing, as, when several diagrams e same engine representing varying loads are to be calcu- he value when once obtained will answer for all, the speed practically the same in each case. The area of the piston- enerally ignored in such calculations, though it will dimin- area of one side of the piston about $\frac{1}{40}$.

custom of dividing the indicator card into ten ordinates n generally adopted by engineers because ten is the most



nt number for a divisor, since the process of dividing by ts merely of pointing off one decimal. The M. E. P. is ed by dividing the aggregate length of the ordinates by mber, and multiplying the quotient by the scale of the . The following instructions will be found useful to per- ccustomed to make the calculation.

— *Divide* the card into ten equal parts, as shown by the ines *in the above diagram*, after which draw a line exactly through the centre of each space, as shown by the full lines 1, 3, etc.. Then draw the dotted line *A A*, representing the atm pheric line, also draw the full line *V V*, representing the zero, vacuum line, which is equal to $14\frac{7}{10}$ pounds, below the atm pheric line; then measure the card at the following points:

The initial-pressure as shown at . . . . . .
The pressure at the point of cut-off . . . . *C.*
The terminal-pressure at . . . .
The pressure at the end of the cushion . . .

Next measure the full lines, or ordinates 1, 2, 3, etc., wi slip of paper, marking with a sharp pencil or the point of a the length of each, until it contains the sum of all their len which in this case will be found to be 11·75 inches; then, the mean length $\frac{11·75}{10} = 1·175$ inches, and the mean-pre $1·175 \times 16$ scale of the indicator $= 18·80$ pounds; the co rendering of a card would be as follows:

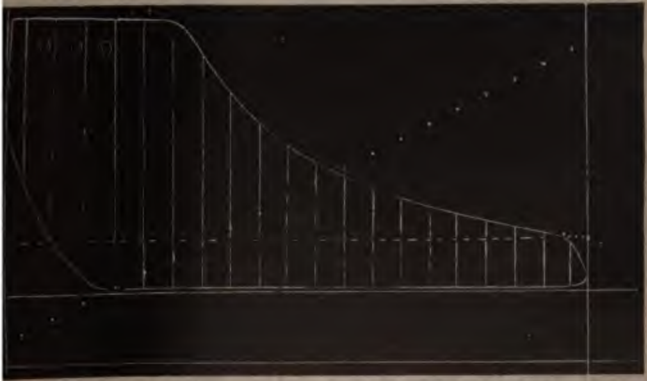
Initial-pressure,	(above zero)	=	*I.*	=	32·0lb
Pressure at cut-off	" "	=	*C. O.*	=	28·0 "
Terminal-pressure	" "	=	*T.*	=	17·0 "
Mean back-pressure	" "	=	*B.*	=	5·6 "
Pressure at end of cushion	(above zero)	=	*C.*	=	18·5
Mean effective pressure		=			18·

Suppose the diagram to be taken from one end of a 50 inches in diameter (with a stroke of 48 inches), ma revolutions per minute, and the area of piston to be 1963·5 inches, then $1963·5 \times 18·8 = 36,913·8$. This pressure the piston throughout the stroke, 48 inches, 50 times a and the work done on one side of the piston in each minute be $36,913·8 \times 50 \times \frac{48}{12} = 7,382,760$. Now, if another diagra taken from the other end of the cylinder, and the measur be the same, the total work done by the engine each minute

he $\frac{7,382,760 \times 2}{33,000} = 447$ horse-power.

ie analysis of diagrams in this work, the custom of dividing gram into ten ordinates is sometimes departed from, because, first place, ten ordinates are not considered enough, in all o insure accurate calculation; and, secondly, because, when the r of ordinates is made the same, or one-half, one-third, or irth as many as there are pounds per inch in the scale diagram, the calculation is, if anything, simpler than the ocess, since the sum of the ordinates, as measured on the f paper in inches, is the mean effective pressure at once, he number of ordinates equals the scale, and in other cases s the same relation to it that the number of ordinates does scale. Ten ordinates may be used, however, for such scales divisible by 10.

oose the scale to be 60, and the number of ordinates 10, it the sum of their lengths is 7 inches. According to the process, $\frac{7}{10} = \cdot7 \times 60 = 42$ lbs.; by the latter method, sup- the number of ordinates to be $\frac{1}{6}$ of the scale, the process is $6 \times 7 = 42$; that is, the mean effective pressure would be es the sum of the length of the ordinates, if the scale is six ieir number.



ose the scale *to be 40 lbs* per inch, one-half of that num- *20 ordinates, as shown* in the above diagram, are used;

and suppose the sum of their lengths is found by the process o measurement above given to be 15·3 inches, then twice that nu ber will be the mean effective pressure in pounds per square inc or $15·3 \times 2 = 30·6$ lbs. Suppose the cylinder of an engine is 2 inches in diameter, 40 inch stroke, running at a speed of 75 rev lutions, or 500 feet per minute; the area of such a piston wou be 314·16 square inches; hence, $\frac{314·16 \times 500}{33000} = 4·727$ horse-pow for each pound of mean effective pressure. The latter being 30 then $30·6 \times 4·727 = 145,656$, the indicated horse-power.

The Indicated Horse-power may be found more accurately measuring the exact area of the space enclosed by the diagr This may be done with the aid of the *planimeter*, which is describ on pp. 566–569. Having determined the area of the diagr proceed as follows:

Rule for finding the mean effective pressure from the area the diagram.

Multiply the area of the diagram in square inches by the sc of the spring and divide the product by the length of the diagr in inches. The quotient will be the mean effective pressure.

Rule for finding the indicated horse-power.

Use the mean effective pressure thus obtained and proceed above, or more exactly:

Take the area of the head end diagram and multiply it by t scale of the spring, and the ratio of the length of the stroke feet to the length of the diagram in inches. This product is t work done per square inch of piston area each stroke, and hen it must be multiplied by the piston area in square inches and t number of revolutions per minute and divided by 33,000, to gi the horse-power of the head end.

Next, take the area of the crank end diagram and proceed the same way, except that the area of the piston-rod must be ducted from the area of the piston. This result will give t *horse-power* of the crank end, which, added to the first, will gi *the total* indicated horse-power of the engine.

Example.—In diagram No. 21, on page 554, suppose that *T* resents the head and *B* the crank end, and suppose that the as of these two, as measured by the planimeter, are 4.087 and 75 square inches respectively. The scale of the spring is ty pounds to the inch and the piston-rod is four inches in meter. Required the mean effective pressure and the horse- er of either end and the total indicated horse-power?

ince the length of the diagram is 4½ inches we have

$$\text{M. E. P. (head end)} = \frac{4.087 \times 30}{4.5} = 27.25 \text{ pounds.}$$

$$\text{M. E. P. (crank end)} = \frac{4.275 \times 30}{4.5} = 28.50 \text{ pounds.}$$

$$\text{M. E. P. (average)} \qquad = 27.875 \text{ pounds.}$$

$$\text{I. H. P.} = \frac{27.875 \times 720 \times 1847.45}{33{,}000} = 1123.36$$

if the horse-power is calculated from the diagram direct, tak- into account the area of the piston-rod, the ratio of the length troke to that of the diagram is $\frac{6}{4.5} = 1.333$, and the area of the on-rod is 12.566 square inches, hence

$$\text{I. H. P. (head end)} = \frac{4.087 \times 30 \times 1.333 \times 1847.45 \times 60}{33{,}000}$$

$$= 549.2$$

$$\text{I. H. P. (crank end)} = \frac{4.275 \times 30 \times 1.333 \times 1834.88 \times 60}{33{,}000}$$

$$= 570.5$$

$$\text{I. H. P. (total)} = 549.2 + 570.5 = 1119.70*$$

The calculation on page 555 for the same engine gives 1123.36 H. P., ead of 1119.70 *H. P.* *The latter* is the more accurate because the diame- *f the piston rod is taken into* consideration.

In order to make this calculation more clear let us assume when the cut-off takes place later in the stroke the engin creases in speed to 80 revolutions per minute and the p increases to 2000 indicated horse-power. Neglecting the i ence of the area of the piston-rod, what must be the mean eff pressure under these conditions?

Total work done per minute =

$$33{,}000 \times 2000 = 66{,}000{,}000 \text{ foot-pounds.}$$

Work done per stroke =

$$\frac{66{,}000{,}000}{2 \times 80} = 412{,}500 \text{ foot-pounds.}$$

Space traversed by piston per stroke = 6 feet.

Mean force acting on piston =

$$\frac{412{,}500}{6} = 68{,}750 \text{ pounds.}$$

Area of piston,

$$0.7854 \times 48.5 \times 48.5 = 1847.45 \text{ square inches.}$$

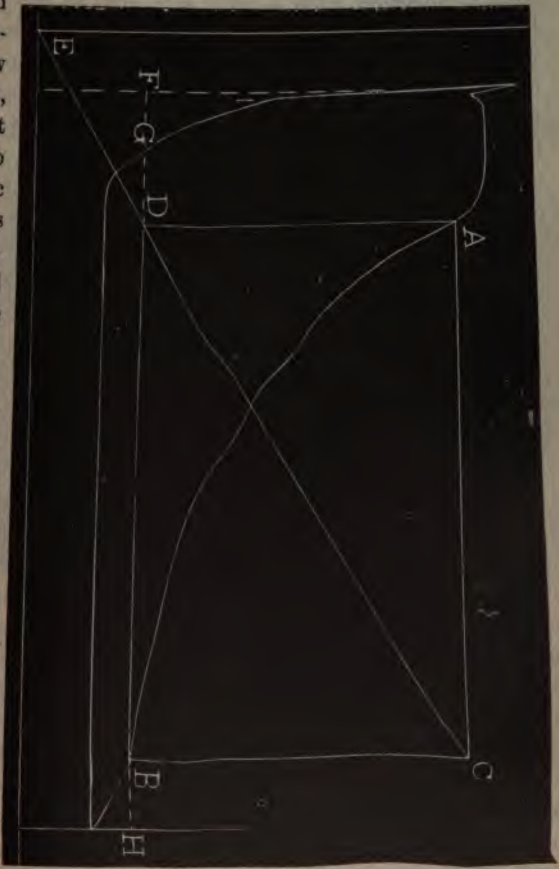
Mean force on each square inch of piston area = mean eff pressure =

$$\frac{68{,}750}{1847.45} = 37.2 \text{ pounds per square inch.}$$

The net or brake horse-power of a steam engine may be from the indicator diagram in the following manner:

Take an indicator diagram when the engine is running full load, and another when it is running with no load exce internal friction. The latter is called the *friction diagram.* duct the area of the friction diagram from that of the full diagram, and from this net area calculate the mean eff pressure. The latter, used in the formula for horse-power, give the actual horse-power available at the shaft. The power consumed by any machine which the engine is driving be found by taking diagrams with the machine on and off lating the horse-power with the difference of the two

ormula for Finding the Theoretical Clearance when the Scale is known.



rom two points in the expansion curve, as *A B*, the former
arly and the latter as late as possible consistent with the cer-
ty that both
n the expan-
curve, draw
ertical lines,
and *B C*, at
angles to
atmospheric
acuum lines
the horizon-
nes, *A C* and
forming the
lelogram, *A*
B. Then,
gh *C D*
a diagonal
continuing
wnwards till
tersects the
m line at
d from this
draw a ver-
line, which
epresent the
nce. It will,
e majority
es, indicate
clearance
actually ex-
but if, as is
mes the case with large engines of good construction and

in good condition, the diagram agrees closely with exact theo the clearance thus shown will be less than the actual.

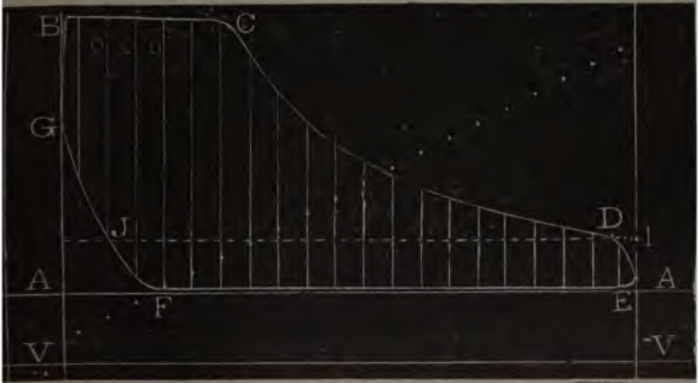
On theoretical grounds, there should be no clearance at all any space between the cylinder-head and the piston at the en the stroke must be filled with steam. But in practice it is im sible to dispense with it, since any wear of the parts must the stroke, and foreign substances, such as grease or water, find their way into the cylinder. The loss resulting from clear in cylinders may be lessened by judicious design, since, if pression takes place as the piston approaches the end of its st it serves to raise the temperature of the steam enclosed, re the quantity of new steam required, and brings the mome of the piston to rest, thereby lessening the shock on the cra

Formula for Finding the Scale of a Diagram whe Clearance is known.

Draw a line representing the clearance; then proceed, as to draw the parallelogram, *A C D B*, and continue its dia *C D*, till it intersects the clearance line, as at *E*. From the est point to this point of intersection, generally below, (whi its distance from the atmospheric line, will represent the pr of the atmosphere, according to one of the scales in use,) the vacuum line which fixes the scale. For instance, suppo intersection occurs about $\frac{7}{16}$ of an inch below the atmos line. The nearest point below that point at which a vacuun can be located to correspond with any of the usual scales i corresponding with the 30 lbs. scale, or a little less than $\frac{1}{2}$ If, however, there be reason to suspect that the actual scale from 30 to 40, (32, for instance,) this method will not dete it with certainty, but it will approximate it when the diff scales used are known to differ from each other to the exte 10 to 20 lbs. per inch. No method can be relied upon when a limited length of the expansion curve is available, or when *much distorted* by vibration, or other defects in the perform *of the instrument.*

Indicator Diagrams.

All indicator diagrams are the perfect pictures of the perform-
ces of the engines from which they are taken, provided the in-
cator is in good order. There are two senses in which a diagram
said to be perfect or imperfect. First, it may be in perfect con-
mity to existing conditions, as clearance, load, steam-pressure,
., though all of these conditions may be far from the best; or,
ond, it may not only conform to the above conditions, but it
y represent the best attainable conditions, which would include
clearance at all, which is unattainable.



Explanatory Diagram No. 1.

n diagram No. I, *B C* shows the steam line; *C*, point of cut-off;
D, expansion curve; *D*, exhaust; *D E*, exhaust line; *E F*, counter-
ssure line; *F*, point of exhaust-closure; *F G*, compression curve;
B, admission line; *A A*, atmospheric line; *V V*, vacuum line;
H, line representing the clearance; 0 0 0, ordinates for ascertain-
g the average pressure; *I*, continuation of the expansion curve to
d of stroke, to give the terminal-pressure for the purpose of calcu-
ting theoretical consumption; *J*, the point in the compression curve
here the *pressure equals the terminal*; consequently, I J is the pr
rtion of the whole stroke taken as the measure of the consumpti

Diagram No. 2 was taken from a Buckeye automatic engine 22 × 44; piston speed, 520 feet per minute; sca

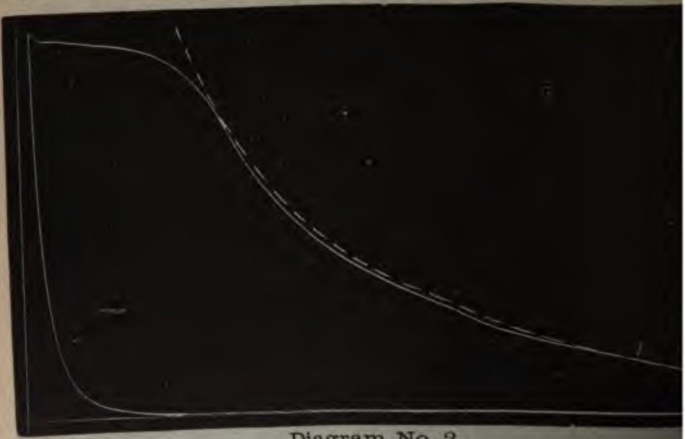


Diagram No. 2.

clearance, 1·75 per cent.; mean effective pressure, 36 lbs. I very perfect performance both of the engine and indicator,

Diagram No. 3 was taken from a locomotive built at the B

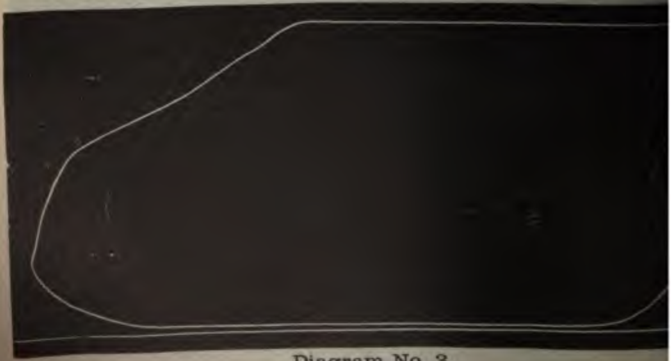


Diagram No. 3.

motive Works, for the Pennsylvania Railroad Compa the Philadelphia and Erie Railroad. Diameter of c

8 inches; stroke, 22 inches; speed, 93 revolutions per minute; oiler-pressure, 115 lbs. per square inch; initial-pressure, 100 lbs.; ean effective pressure, 86·60 lbs.; clearance, 4 per cent. At the ime the diagram was taken, the engine was pushing a train of 15 oaded cars, whose gross weight was 302 tons, throttle-valve wide pen, against a grade of 74 feet rise per mile. Adhesion per ton f load 600, resistance per ton due to grade 35·7 lbs. The slight ounding of the induction corner was probably caused by too uch pressure on the pencil, which prevented it from rising till fter the paper started to move. The diagram is very good. The xpansion curve, as far as can be observed from its limited extent, s correct, and its compression curve very nearly so.

Diagram No. 4 was taken from a Wardwell valveless engine n exhibition at the Centennial Exposition held at Philadel-hia. The conditions under which the diagram was taken are ot specified, but it will be observed that the exhaust-port opens uite late and quick, which explains the fact that the curve is all n the lower corner. The cut-off is quick and sharp. The induc-on and compression lines are also good. The lateness of the ex-aust is a necessary *result of* the movement which produces it, as *is effected by a partial* rotation of the piston-head, derived from

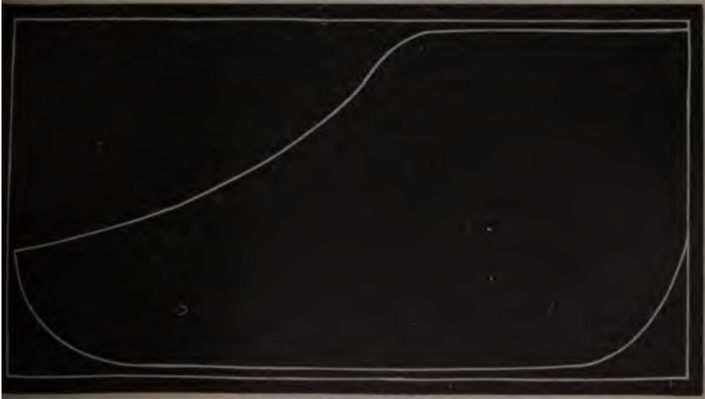
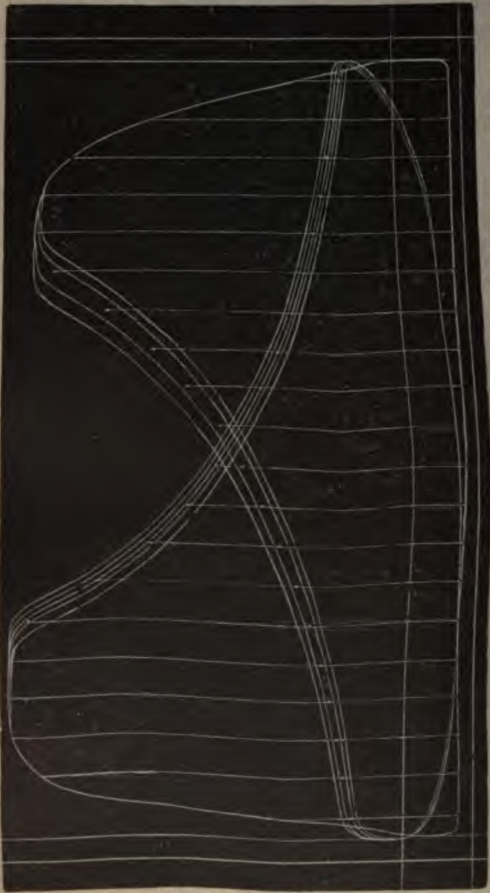


Diagram No. 4.

the lateral vibration of the connecting-rod, which gives a movement exactly equivalent to that of an eccentric without angular advance.

Diagrams No. 5 were taken from an old Corliss engine that had been running in the penitentiary at Jackson, Michigan, for about 25 years. Scale, 40; clearance about 3 per cent.; mean effective pressure, 47·5 lbs.; mean of the two ends, 47½ lbs. It possesses no special interest, save to show the effects of adjustment due to long wear and use, without the application of an indicator or any other test. The excessively late induction would cause a perceptible loss of useful effect in the steam. The exhaust is much less perfect from one end than from the other, and much of the benefit of the vacuum is thereby lost. The pencil was held on during several revolutions, and, the governor being over-sensitive and fluctuating, different lines were drawn at each revolution.



Diagrams No. 5.

Diagram No. 6 was taken from a Harris Corliss engine oper-
ting at the Cincinnati Industrial Exposition of 1875. Size, 16
< 48; speed, 60 revolu-
ions, or 480 feet of piston
peed per minute. Both
he isothermal, *I*, and the
diabetic curves are drawn.
n tracing the latter, the
ollowing process was used.
he horizontal lines, *A*, *B*,
, *D*, *E*, *F*, *G*, represent to-
al pressures (above vacu-
m) of, respectively, 90, 80,
0, 60, 50, 40, and 30 lbs.,
he volumes of which are
98, 333, 378, 437, 518,
40, and 838. At the point,
I, where the curve termi-
ates, the total pressure is
9 lbs., the volume of which
s 1290. Now, it is evident
hat if the distance, *H J*,
which is 4·7 inches, repre-
ents 1290, the distance,
 J, representing 838,
the volume of 30 lbs.,)
ill be proportionately as
uch shorter than *H J*
s 838 is less than 1290.
ence, the formula, 1290 :
7 : : 838 : 3·05, or
$\frac{7 \times 838}{1290} = 3{\cdot}05$, will give
is distance *(3·05) from*
e *clearance line, J, to*

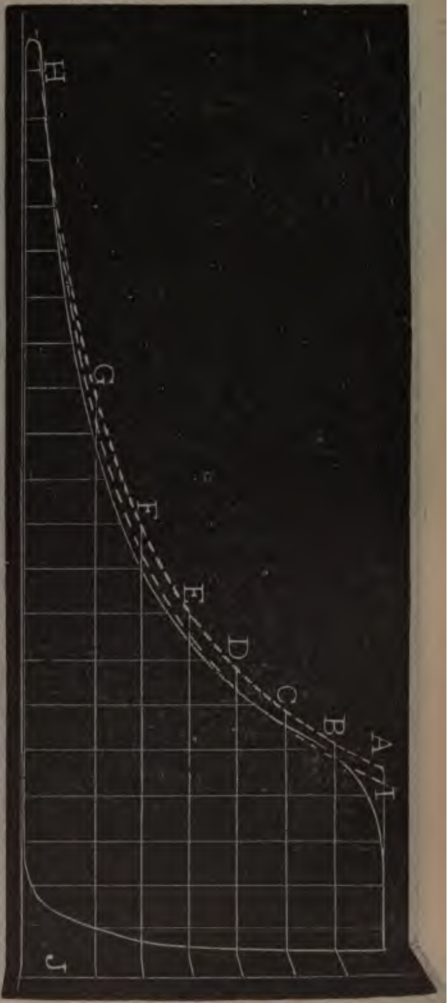


Diagram No. 6.

that point in the curve which shows a pressure of 30 lbs. In manner the formula for the point, *F*, will be $\frac{4·7 \times 640}{1290}$ fo $\frac{4·7 \times 518}{1290}$, and so on for the other lines, *D*, *C*, *B*, *A*. The going process may, however, be shortened.

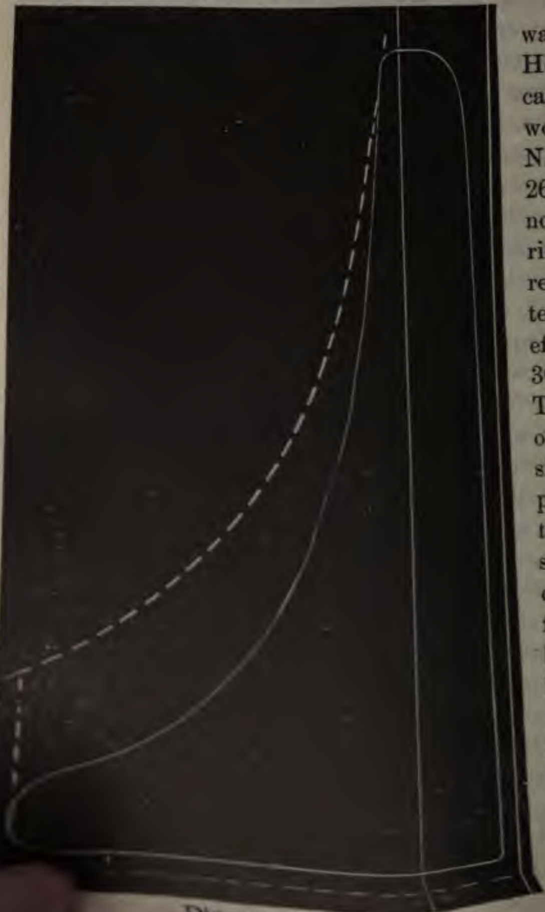


Diagram No. 7.

Diagram N
was taken fro
Holly engine
cated at the
works of Roch
N. Y. Size,
26·9 inches;
not given, but
ries greatly, a
regulated by t
ter-pressure;
effective pr
30 lbs.; scale,
The cut-off
of these engin
sist of a sing
pet valve pla
the cover
steam-chest,
cuts off the
for both
hence, all th
in the chest
ject to ex
along with
the cylinde
has the effec
mous clea
the diagra
theoretical

own is not based on the actual clearance subject to expa
ut on a reasonably small amount, not greater than the av
f true automatics
f good construction;
onsequently, it is not
test of the conform-
y of the curve to the
ctual conditions, but
ther a means of
omparing the eco-
omical results of
ch an arrangement
ith engines of the
est automatic type.

Diagram No. 8 was
ken from a Wheel-
ck automatic cut-off
ngine on exhibition
t the Centennial Ex-
osition. Size, 18 ×
8; clearance, 4½ per
ent.; scale, 30; mean
ffective pressure, 12;
iston speed, 50 revo-
tions, or 400 feet per
inute. *A* is the adi-
batic and *I* the isoth-
rmal curve, both be-
g based on actual
erminal-pressure.
he diagram is quite
ood for a light load,
ough the very slight
ompression *is not in*
cordance with the weight *of* opinion as to what constitu
ctice.

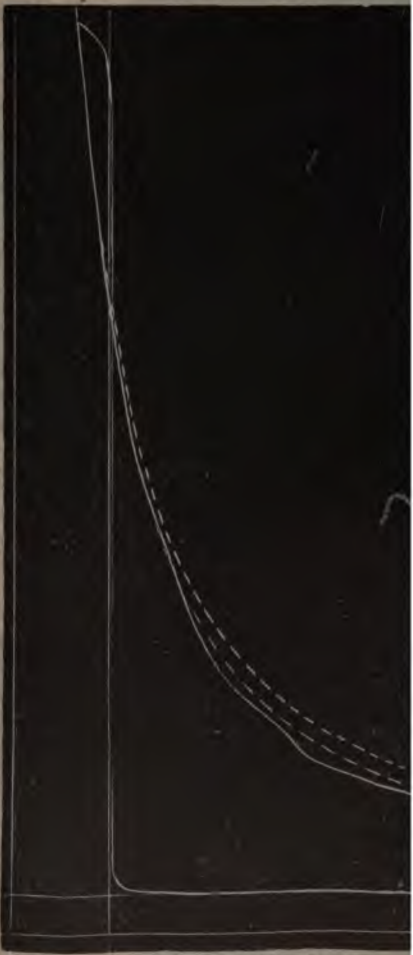
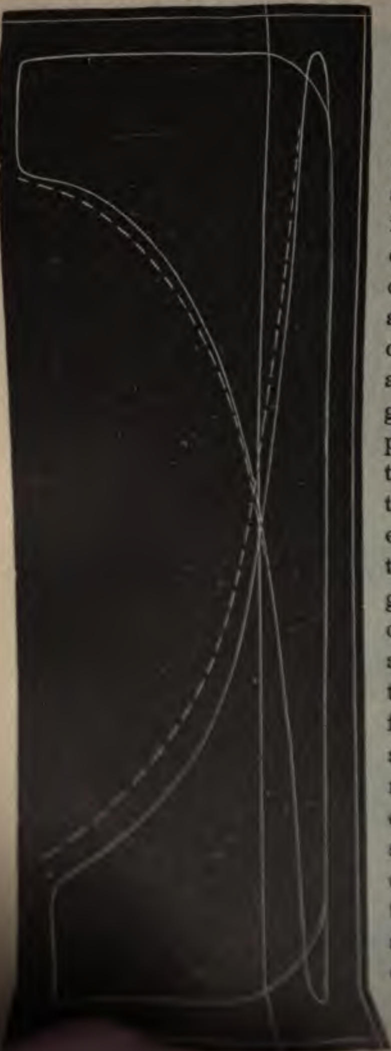


Diagram No. 8.

Diagrams No. 9 were taken from a **Cummer** slide-valve



[illegible] No. 9.

with riding cut-off, built
troït, Michigan. Size, 26
inches; speed, 80 revoluti
480 feet per minute; sca
mean effective pressure n
en; clearance is unknown,
suming it to be 4 per cent.,
is about what its construct
quires, the theoretical cu
one end shows correct pe
ance, but that at the other
considerable deviation. I
a case, taking the size of t
gine into consideration, t
planation of this defect l
tween two suppositions, 1st
the cut-off valve leaked
end and not at the other;
that the volume of cleara
greater at one end than
other. If the engine had
a small one, the suppositi
the escape of the expanding
from the right-hand end th
a leaky slide-valve would
missible; but the curve a
end is just what an engine
size given should produc
out leakage of any kind;
the left hand is the one t
attention is directed for th
of the difference between th
and the supposition of a
cut-off valve is the mor
able one.

gram No. 10 was taken from one of a pair of 16 × 30 inch slide-valve engines, which were attached to the same shaft ranks at right angles to each other. The piston speed was et per minute; mean effective pressure, 32·3. The sudden ation of the compression curve with a descending hook sug-

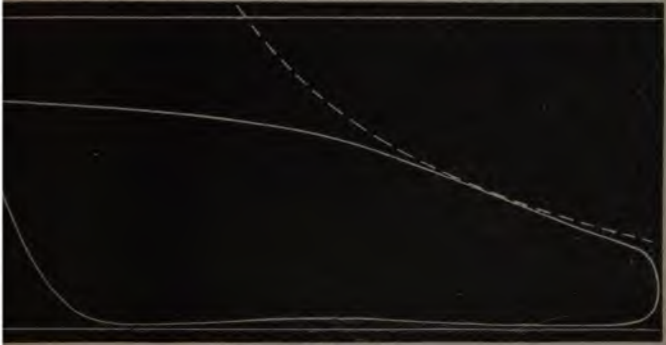


Diagram No. 10.

eakage of the piston or valve. The more rapid fall of the sion curve than theory requires, strengthens this supposition, oints to the piston as the source of the trouble. The rise of r-pressure in the middle of the return stroke is due to the on of the exhaust of the other engine.

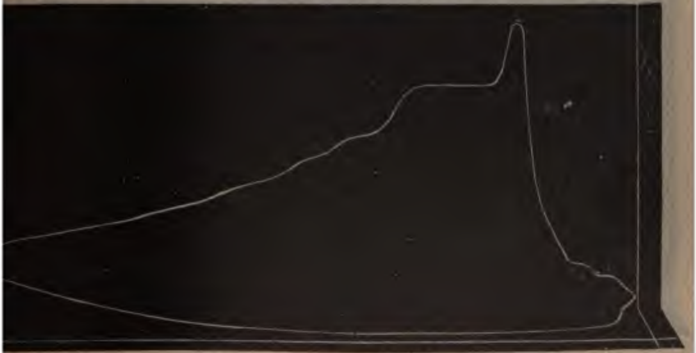
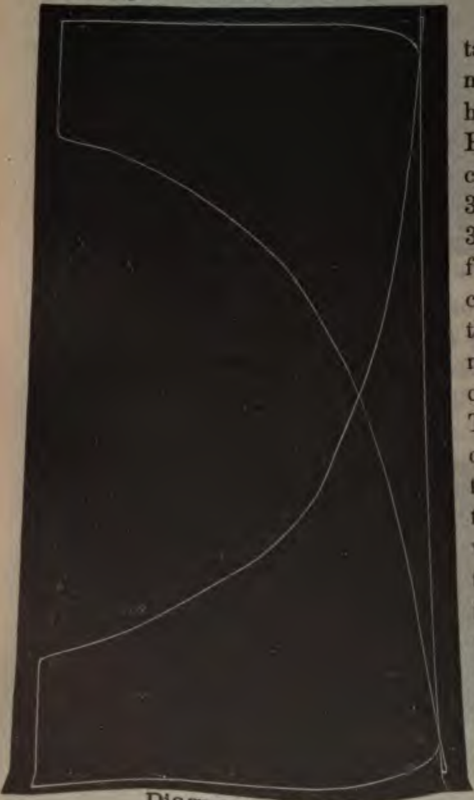


Diagram No. 11.

am No. 11 *was taken* from an engine, 18 × 36, in a mi in Detroit, Michigan. The cut-off was effected by a special off valve above the steam-chest, operated by a Kendall's pat governor, which varies the throw and advance of an eccen on the shaft by an arrangement similar to that of the link-mot of a locomotive. The most striking defect is the extremely induction, showing a displacement of the eccentric, leading loss of about one-sixth of the stroke. The exhaust is too evidently from the same cause.

Diagrams No. 12 taken from a Brown matic cut-off engine on hibition at the Center Exposition. Diameter cylinder, 15 inches; str 38; revolutions, 65; 30 lbs. They show won ful conformity to theo cal requirements, and the engine and indic must be in the most pe order to produce such The unusually sharp off corners are due to tain extent to the fact the induction and cu valves are of the gri type, and that the indi is of an improved pa with exceptionally moving parts; but nev less there is an air picion about them, th leave doubts of their uineness in the minds telligent engineers who understand the action of the team-engines.



Diagrams No. 12.

Diagram No. 13 was taken from a John Cooper engine, built nder the Babcock and Wilcox patent, at Mount Vernon, Ohio. iameter of cylinder, 20 inches; stroke, 36 inches; boiler-press-re, 55 lbs. per square ch; speed, 60 revolu-ons per minute; scale, lbs. per square inch. shows no imperfec-ons worthy of note, ex-pt the imperfect re-ntion of the compres-on-pressure, owing un-oubtedly to leakage ther of the piston or ide valve. Such a de-ect is a very common ne, and may appear hen no other evi-ences of leakage exist, which case it is prob-ble that, if the com-ression escapes by the iston, the leakage ex-sts at the end of the troke, or, if it escapes y the valve, only the ortion which retains he compression-press-re fits imperfectly. In e present case the ompression curve com-nences promptly, but ccumbs completely, and falls again before admission, show-g that the leakage commences suddenly near the end of the troke.

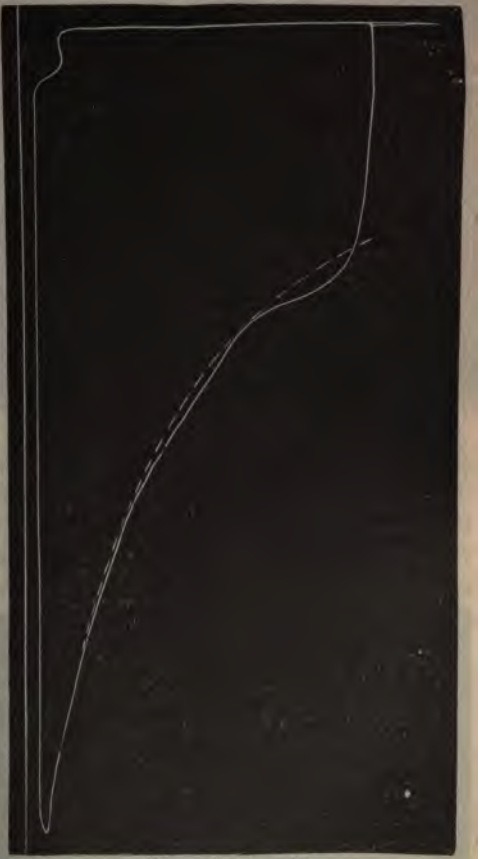


Diagram No. 13.

Diagram No. 14 was taken from a 9 × 15 high-pressure si slide-valve engine. Speed, 190 revolutions per minute; scale,

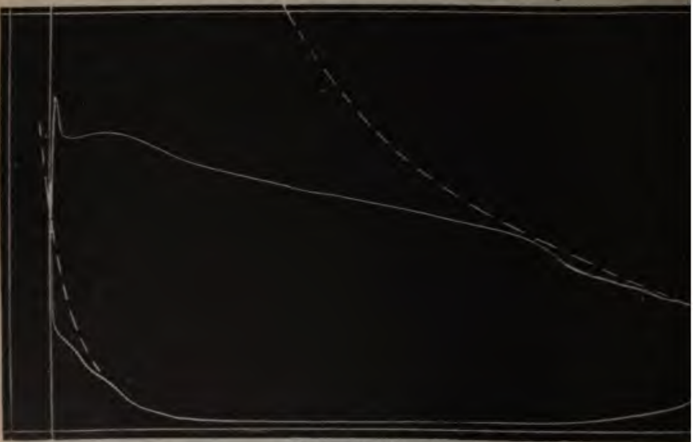


Diagram No. 14.

clearance, 6·4 per cent.; mean effective pressure, 41 lbs. It wil noticed that its events occur late, which defects arise from coun pressure, indicating obstructed exhaust and imperfect rise in compression-pressure, suggesting leakage of either the valv piston by which the compression-pressure has escaped.

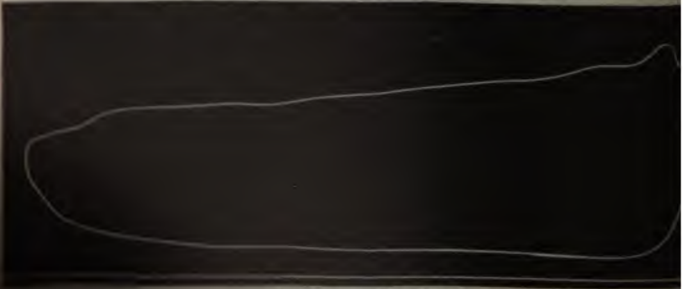


Diagram No. 15.

No. 15 was taken from the same engine. Its defec as shown by its late cut-off, late and insuffici aust, and its excessive counter-pressure, all tending to ext ant fuel consumption, speak louder than words of the vital im nce of an intelligent use of the indicator by engine builders cularly when perfect- g new designs and onstructions. The ounter-pressure was artly due to a con- racted exhaust-nozzle sed to create draught; ut, even if it had had mple exhaust capac- ty at all points ex- ept at the nozzle, the ounter-pressure cre- ted by that ought not o have exceeded one r one and a half to wo pounds per square nch.

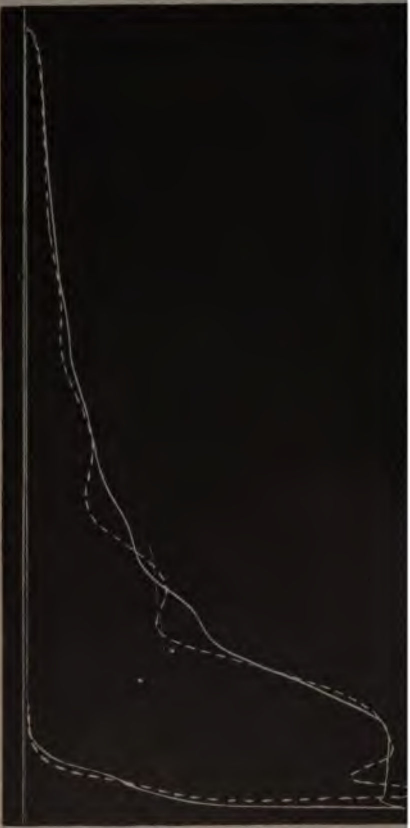


Diagram No. 16.

Diagram No. 16 is n exact transfer from wo diagrams taken parately from the me end of the cylin- er of an automatic it-off engine. The otted lines represent e card made by the ichards, while the lain lines represent at made by the Thompson, indicator. A comparison re e fact that the correct average pressure cannot be ascert om *a diagram which is distorted* by vibration, and also t *dications are deceptive* as to admission, cut-off, and com

Diagrams Nos. 17 and 18 were taken respectively from the high- and low-pressure cylinders of the compound engines of the steamship Pennsylvania, of the American Line, built by Cramp & Sons, marine engineers and naval architects of Philadelphia; speed, 58·3 revolutions per minute. The diagrams present no defects; the slight difference in the mean pressure of the two ends of each card (as in the case of all vertical engines) is due to the unbalanced weights of the reciprocating parts.

The theoretical clearance is about 10 per cent.; and, as this is probably not far from the actual, the expansion curves show very correct performance. The amount of vacuum shown is 10 t 10½ lbs., which is above the average of marine engines.

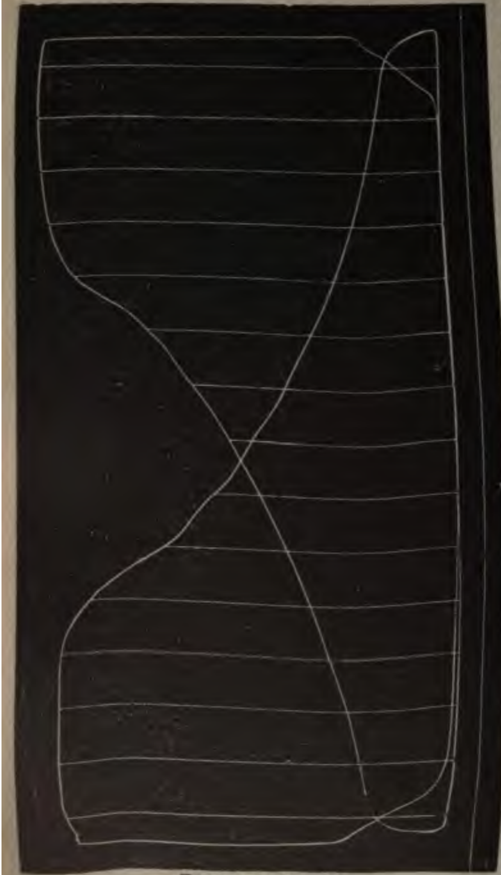


Diagram No. 17.

As these engines are said to be more economical than any *heretofore* used on ocean steamers, a calculation of their *theoretical economy* will not be without interest. Taking the steam us y the small cylinder as the measure of consumption, the first rocess is to find for it the equivlent of the mean-pressure acting n the large piston. The area f the small cylinder is 2574·1975 quare inches, and that of the rge one is 6379·4238 square ches. The M. E. P. of the mall cylinder is 33·25 lbs., and hat of the other 9·25 lbs. The ule is to multiply the area of he large piston by the meanressure acting on it, and divide he product by the area of the mall piston. But, in the present case, it will involve less labor o perform the division first, hat is, to divide the area of the arge piston by that of the small ne, and multiply the quotient y the M. E. P. of the large one. hus, 6379·4238 ÷ 2574·1975 × ·25 = 19·33 lbs., which, added o the M. E. P. of the small cylnder (33·25 + 19·33 = 52·58 bs.), gives for it the equivalent f both, 52·58. Then the volme of the average terminal (28 bs.) being 895, the calculation ill be as follows: $\frac{859·375}{895 \times 52·58}$ = 16.2 lbs. From this the deuction for compression will be bout 3 per *cent., or ·48 lbs.,* leaving (16·2 — ·48) 15·70 lbs. per *H. P. per hour, which justifies* theoretically the claim made

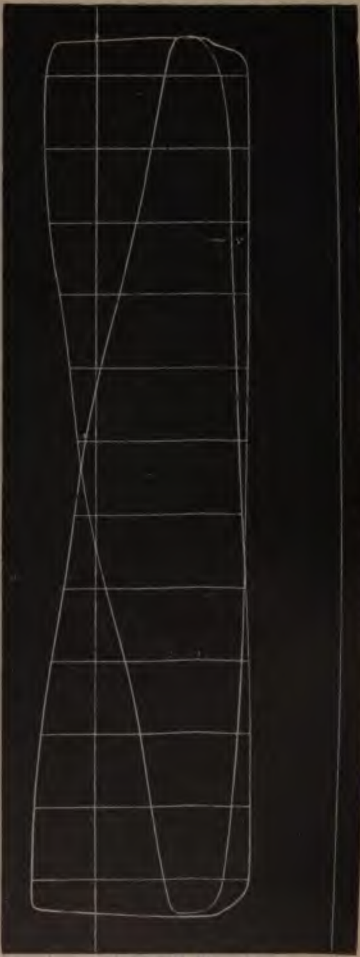


Diagram No. 18.

ıal-pressure of both ends of the high-pressure cylinder is
ıbove vacuum); volume, 550. Of the low-pressure cylinde
lbs. above vac-
volume, 2100.
quivalents for
ylinder of the
ned power of
ıre as follows:
he high-press-
linder, 43 125
·64 = 86·765.
ıe low-pressure
ler, 14·25 +
2 = 28·332.
these data, the
ıtion of the
tical rates of
consumption
for each cyl-
ıs follows: For
igh-pressure
er $\frac{859\cdot375}{86\cdot765\times550}$
lbs. per indi-
horse-power
our. For the
essure cylin-
$\frac{859\cdot375}{\cdot332\times2100}=$
lbs. indicated
-power per

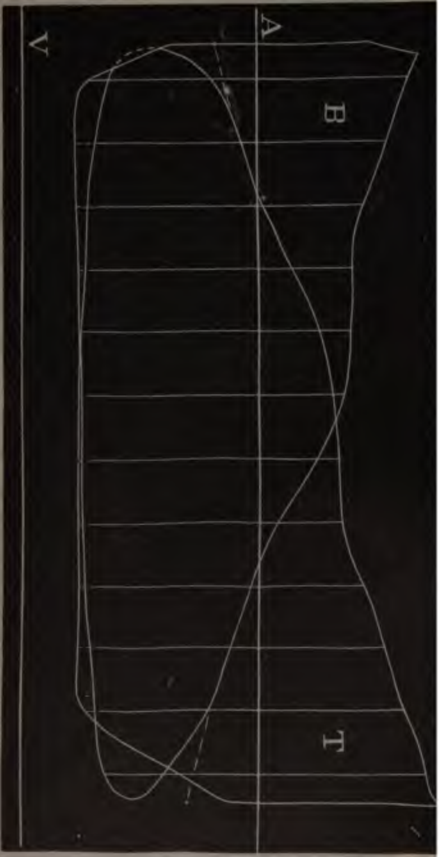
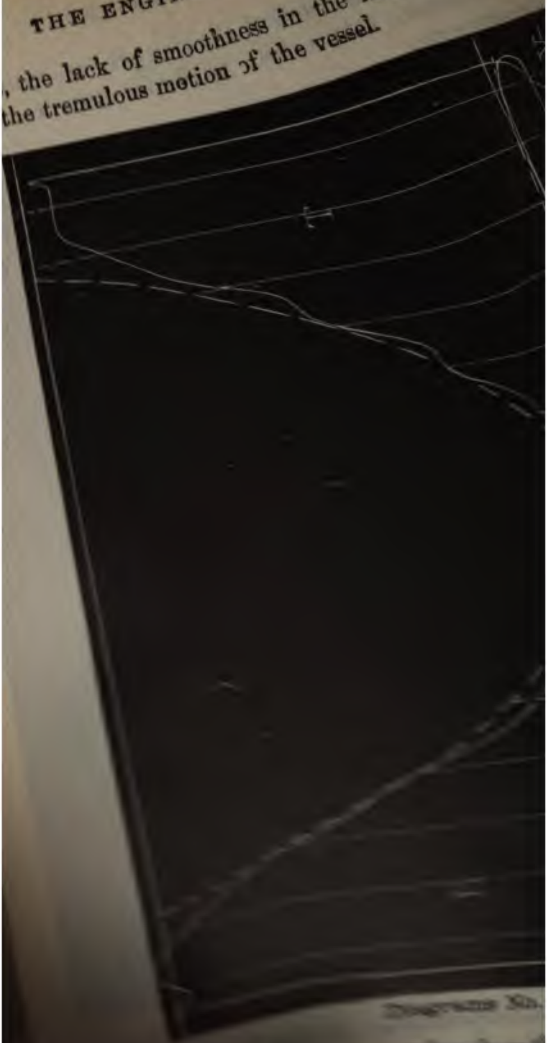


Diagram No. 20.

maximum compression-pressures of each are so ne
to the terminal, that no correction for clearance and cu
e made. The diagrams indicate good performance

, the lack of smoothness in the lines being presum
the tremulous motion of the vessel.



Diagrams No.

[illegible] No. 3 were taken from [illegible]

[illegible]

rty-ninth voyage from New York to Havana. Diameter of inder, 48½ inches; stroke, 6 feet; speed, 60 revolutions, or 720 t per minute; scale, 30 lbs. per inch. The boiler-pressure, which represented by the lines above the diagram, was 72 lbs. per iare inch; vacuum, 23 inches, the equivalent of which is rep ented by the dotted line *V V*. The full line below represents erfect vacuum. The theoretical expansion curves are the adia ic curves, calculated from the table of volumes on pages 39 1 43 of Roper's Hand-Book of Land and Marine Engines. The culations are as follows:

Assuming the clearance to be 5 per cent., the mean-pressure of theoretical diagram around the diagram *B*, which is based on line *V V*, will be 32·8 lbs. The mean effective pressure of ual diagram *B*, 28·5 lbs. Percentage realized of the full theo ical value of the boiler, terminal, and condenser pressures, $\frac{\cdot 5 \times 100}{32{\cdot}8} = 86{\cdot}88$. Parallel calculations for the diagram *T* give following:

Mean-pressure of theoretical diagram, . . .	31·8 lbs.
Mean effective pressure of actual diagram, . .	27·25 lbs.

Percentage realized, $\frac{27{\cdot}25 \times 100}{31{\cdot}8} = 85{\cdot}68$.

The mean of both ends is as follows:

Mean-pressure of theoretical diagrams, . . .	32·3 lbs.
Mean effective pressure of actual diagrams, . .	27·875 lbs.

Percentage realized, $\frac{27{\cdot}875 \times 100}{32{\cdot}3} = 86{\cdot}3$.

The area of the cylinder being 1847·45, and the piston speed 0 feet per minute, the horse-power value, or the horse-power for ch pound of mean effective pressure, is calculated as follows: $\frac{47{\cdot}45 \times 720}{33000} = 40{\cdot}3$. The mean effective pressure being 27,875 ., the total horse-power is $27{,}875 \times 40{\cdot}3 = 1123{\cdot}36$. The ter nal-*pressure is 13 lbs., the* volume of which is 1842, and the theoretical rate of water consumption will be found as follo

$$\frac{859375}{1842 \times 27{\cdot}875} = 16{\cdot}74 \text{ lbs. per indicated horse-power per hou}$$

The compression-pressure so nearly equals the terminal, no correction for compression and clearance is necessary. The grams are in nearly all respects excellent; the curves, allo for the unsteadiness which is apt to characterize diagrams t from ocean-steamship engines, are remarkably correct; the en was fitted with Corliss valves. The difference of about 2½ between the vacuum attained in the condenser, *V V*, and tha tained in the cylinder is a circumstance which is almost in rable from such a high piston speed. A comparison of the ra water consumption with that of such others as have been culated, will be instructive, particularly with reference to th ative economic merits of simple and compound engines, a que which is yet unsettled. A comparison of the foregoing calcul with the ordinary or long process will be instructive, as sho the correctness of the short method and the vast amount of l saved by it, especially when dealing with large engines.

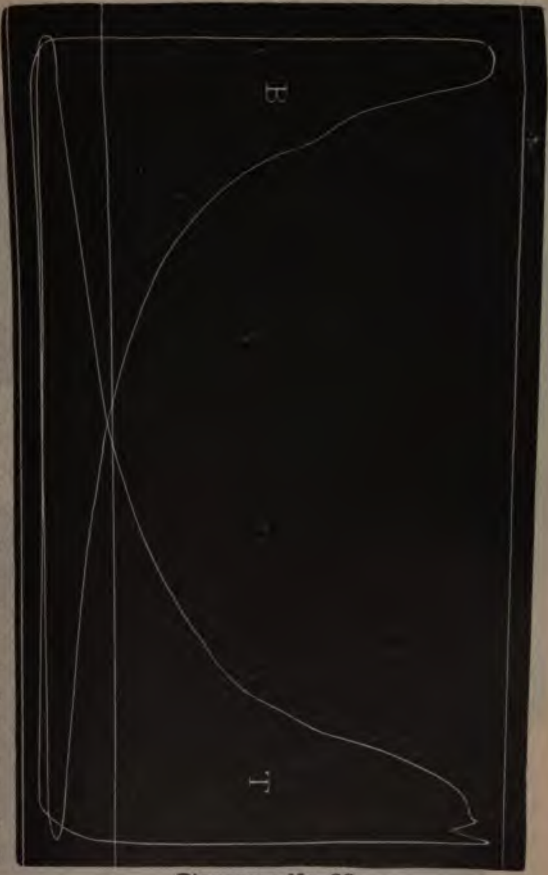
Thus, 720 feet per minute × 60 × 12 = 518,400 inches per l which, multiplied by 1847·45, (area of piston,) = 957,718,080 c inches per hour, as the displacement of the engine.

Then, 957,718,080 ÷ 27·648 (cubic inches of water per po ÷ 1842 (volume of 13 lbs. terminal) = 18,805·476 lbs. of w as its total theoretical consumption of water per hour: th 1123·36 (the indicated horse-power) = 16·74 lbs. per indic horse-power per hour, as before.

In making a complete analysis of diagrams, a statement o mean effective pressure, exclusive of vacuum and that due t vacuum, ought to be given separately. Thus:

Mean-pressure, exclusive of vacuum, . . .	19·37
Mean-pressure due to vacuum, ...	8·5
Percentage of power due to vacuum, ...	

grams No. 22 were taken from the same engine as diagram
21, on the
er's forty-
return voy-
New York
Havana. It
ents con-
bly lighter
han diagram
1, and shows
tainment of
ter vacuum,
re perfect in
nes, and is
ly correct
s expansion
s. The line
e the dia-
s represents
boiler-press-
The calcu-
ns are as fol-
: Mean ef-
ve pressure
iagram *B*, 17
Mean effec-
pressure of
ram *T*, 19·5
Mean of the
18·25 lbs.



Diagrams No. 22.

erminal-pressure of bottom diagram, ... 6· lbs.
erminal-pressure of top diagram, ... 7· lbs.
ean of the two, ... 6·5 lbs.

aking 3600 as approximately the volume of 6·5 lbs. pressure, *ate of water consumption* will be 13·08 lbs. per indicated *horse-power* per *hour*, which, if equalled, has never been exceeded by any other engines in this country, either simple or compound.

Diagrams Nos. 23 and 24 were taken from the simple surface condensing engines of the steamship Knickerbocker, of Crom

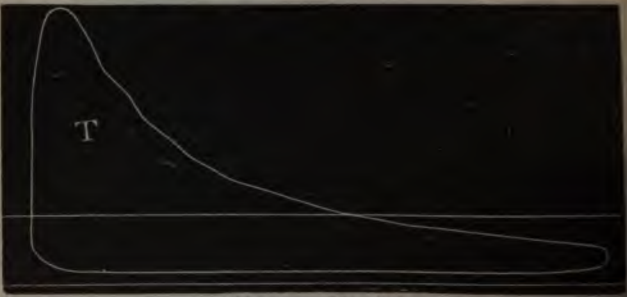


Diagram No. 23.

well's line, and running between New York and Boston. Ma of the conditions could not be ascertained, but the mean effecti

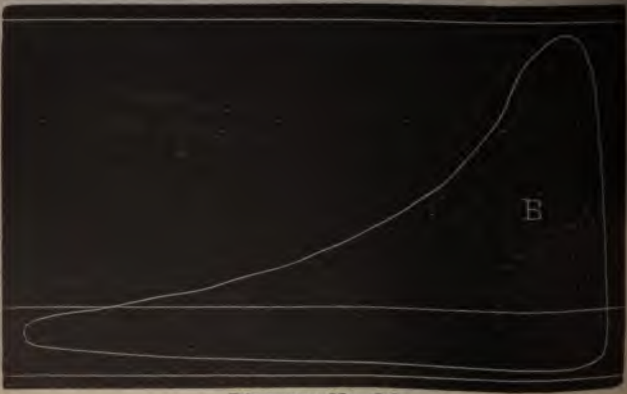
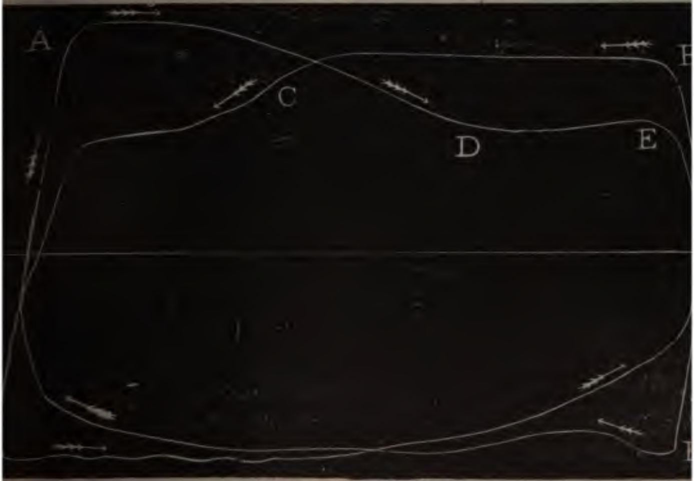


Diagram No. 24.

pressure of *B* appears to be about 29 lbs., and of *T*, 19 lbs. Th calculations of the rate of water consumption give for the card, *B*, 13·74 lbs., and for *T*, 15·55. These very low rates are to some *tent* due to the very perfect vacuum attained. With the exce

on of the tardy induction, or deficient lead, as indicated by th
ward inclination of the induction line, and the great differen
the work represented by the two, they are very perfect. An
nce both features may have been purposely introduced, th
rmer to secure smooth running and the latter to compensate f
nbalanced weight, etc., they should not be hastily pronounce
ults of adjustment.

Diagrams No. 25 present a case of extremely difficult analysi
none of the conditions under which they were taken could



Diagrams No. 25.

certained. The left hand one shows tardy induction, by the i
ination of the admission line to the right. From *A* to *D*,
ill be observed, the pressure falls considerably; but it does n
ppear that the cut-off has taken place, as the curvature of th
ine is upward, which is never the case with a true expansio
urve. From *D* to *E*, it will be seen, the pressure rises slightl
which renders it evident that the steam cannot have been cut o
t any point previous to *E*, unless for an instant, after which
vas readmitted. Supposing the line to correctly represent

actual pressure on the piston, the most probable cause of the ris
in the curve is, that the steam was admitted during the entir
stroke to *E*, but not with sufficient freedom to maintain the press
ure when the piston travel was greatest, or that the connecting
pipe between the cylinder and the indicator was long and tortuou
The right hand diagram is not so peculiar, as it shows a ho
zontal steam-line and a tolerably well defined point of cut-off,
and expansion curve. In both the exhaust is much more free an
prompt than the induction. The best vacuum was obtained
the beginning of the return stroke, *F F*, after which the lin
undulate in a manner not easily accounted for, without an in
mate knowledge of the construction of the engine and the co
ditions attending it.

Diagrams Nos. 26 and 27 were taken from the simple condensi
engine of the steamboat Mary Powell, plying between New York ci
and Albany, which had exceeded in point of speed any other stea
craft on American waters, or in Europe, so far as can be ascertaine
making 25 miles per hour between those points with perfect ea

Diameter of cylinder,	72 in.
Stroke of piston,	12 ft.
Diameter of piston-rod,	8 in.
Diameter of air-pump,	40 in.
Stroke of the air-pump,	62 in.

Very few data could be ascertained, but it seems that the M.
P. of the top diagram was . . . . . . 22·02 lbs.

Of the bottom,	22·23 "
Mean of both,	22·13 "
Terminal of top,	13·5 "
Of bottom,	18· "
Mean of both,	15·75 "
Theoretical clearance of top,	12 per cen
Theoretical clearance of bottom,	17 " "

The water consumption appeared to be about 24·62 lbs. pe
horse-power per hour. The bottom card has the more compres
sion. The size and speed of the engine could not be ascertaine

owell is a splendid specimen of the American beam-en-
-**boat** which some years ago were so great favorites on

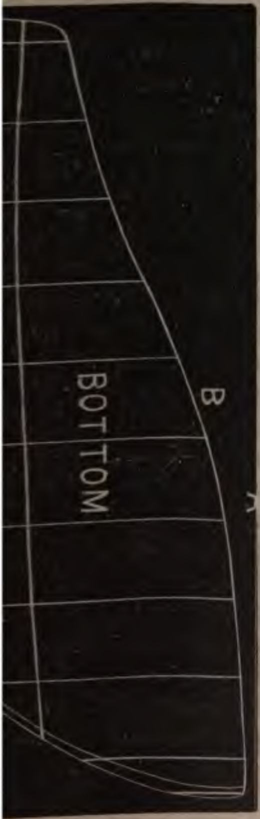


Diagram No. 26.

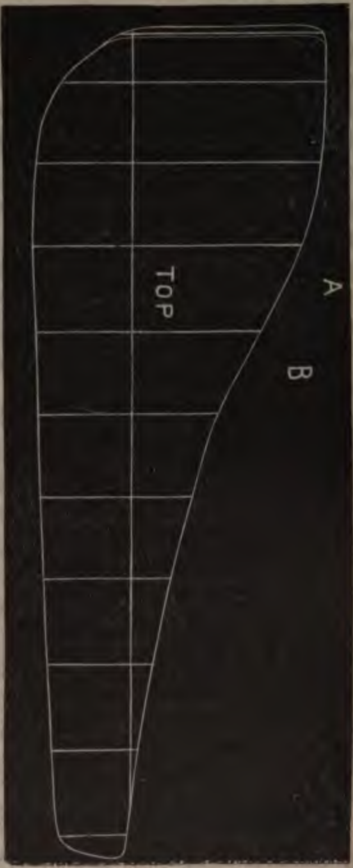


Diagram No. 27.

t of the great speed they were capable of developing, but *are fast disappearing*, and being superseded by another class *es, on account of* inherent defects in their arrangement.

Theoretical Economy.

If the steam used by an engine were known to be saturated, and at the same time free from any excess of water, and if it both entered and left the engine in that condition, it would be easy to calculate from the diagram the amount of water which the engin would use in a given time, supposing it to be practically free from leakage. Under such conditions the expansion and compressio curves would conform rigidly to exact theory, and the total pisto displacement for one stroke, divided by the volume of termin pressure, and the displacement up to any point in the curve di vided by the volume of the pressure at that point, would give th same result wherever the point was taken, which result would the number of cubic inches of water used during that strok Unfortunately, the nature of steam is such that no exact calcul tions of water consumption can be made. Even if its exact dition as it enters the engine is known, as it may be by the cal imeter test, its capacity for receiving and parting with heat is great that its condition changes immediately upon entering cylinder, so that, after deducting the water of supersaturati known to be present before it enters the cylinder, the diagr will still fail to account for all of the remainder. Neverth such calculations are frequently made, and as a means of taining the relative economy of different engines, and of differ loads, pressures, and adjustments in the same engine, they pos great value, since, whatever uncertainty may exist as to the un dicated consumption, it may, so far as the engine is concern be assumed to be the same in each of the cases under comp ison.

When it is desired to approximate as nearly as possible to actual consumption by calculation, a certain amount must added to the theoretical result. This amount varies from 10 to *per cent.*, according as the conditions are more or less favorabl *but when* they are so unfavorable as to require an addition of *per cent.*, they are obviously so bad as to call for repairs anges, rather than elaborate calculations. When the conditions re generally good, a careful examination of them will make it ssible to fix the margin of uncertainty within tolerably narrow mits. A large engine, with well-jacketed cylinder and tight-fitting lves and piston, will generally require at least 10 per cent. ad- tion, independent of the percentage of unevaporated spray, hich may exist in the steam with which it is supplied, and this, less the boiler is so set as to superheat the steam, will require m 10 to 25 per cent. more. In fact, the margin of uncertainty e to the boiler is much greater than that due to the engine, as t only will differently constructed boilers vary greatly in the ount of unevaporated water given off, but great difference will found to exist with the same boiler, according to the height the ter is carried, the rapidity with which it is evaporated, the ount of impurities present in the feed-water, or which have cumulated in the boiler, and many other conditions. Thus a pidly fired generator, containing a large area of heating surface proportion to the amount of water and little steam room and perheating surface, may, and often will, give off nearly or quite much unevaporated water as is contained in the steam. The ly fair way to test the performance of an engine is to test the am as it enters it, both as to moisture and heat. It should o be borne in mind that, according to Trowbridge's tables, the ference between the economy of engines of over ten cubic feet pacity of cylinder and those under one cubic foot, is about 12 r cent. in favor of the larger size.

ow to Calculate Theoretical Rate of Water Consumption.

The total displacement per stroke in cubic inches divided by e volume of the steam at release pressure, and the quotient ltiplied by the number of strokes per hour, will give the total *bic inches used per hour.* This, divided by 27·648, the number *cubic inches of water per pound,* will give the total numbe of pounds used per hour, which, if divided by the I. H. P., will give the result in pounds per I. H. P. per hour. This is the usual method; but, when the *rate only* is desired, a shorter process may be adopted, based on the fact that, from a given diagram, the result would be the same, whether the calculations are based on the actual size of the engine, or some other size is assumed, say a smaller size; as, although the total consumption would be changed, the divisor would also be proportionately changed.

Suppose the engine to be of such displacement as to develop one horse-power with one pound pressure, and that it is driven by that pressure of water instead of steam. It being but one horse-power, its total consumption per hour and per horse-power per hour will be the same. Being driven by water, its displacement will be its water consumption, which will be obtained as follows: A horse-power is 33,000 lbs. lifted one foot high per minute, or 33,000 × 60 = 1,980,000 lbs. per hour, or 1,980,000 × 12 = 22,760,000 lbs. lifted one inch per hour, which would be the displacement of such an engine in cubic inches, and consequently its consumption in cubic inches of water when driven by water. Then, taking 27·648 cubic inches of water per lb., we have 22,760,000 ÷ 27·648 = 859,375 as its rate of consumption in lbs. of water per H. P. per hour. Then, if the pressure were greater than one lb., the amount used would be as many times less than the above, as the pressure was greater than one lb.; and also, if it were driven by steam instead of by water, the amount used would be as much less, as the volume of steam at the terminal pressure was greater than an equal weight of water. It follows that if we divide 859,375 by the product of the mean effective pressure, and the volume of the total terminal pressure of the diagram under analysis, the quotient will be the desired rate, whatever the size and speed of the engine. The use of this constant number renders the operation more easy and short, and, except in the case of the *compound* engine, entirely independent of all data except those furnished by the diagram itself, the scale of indicator being known.

The terminal pressure for this and subsequent rules is foun hen the exhaust takes place before the end of the stroke is eached, by continuing the expansion curve to the end of the troke. In other words, it is not what the pressure may be at the moment of release, but what it would have been if it had not een released until the end of the stroke.

How to apply the rule to diagrams taken from compound enines when the strokes of the two cylinders are equal. Multiply he M. E. P. of the low-pressure cylinder diagram by the area of s piston, and divide the product by the area of the piston of the igh-pressure cylinder. The quotient will be the pressure, which, cting on the low-pressure piston, will be equivalent in energy to hat acting on the high-pressure piston. Then add this quotient o the M. E. P. of the high-pressure cylinder, and with its mean pressure so augmented treat it in all respects as an ordinary diaram. Or the process may be reversed, *i. e.*, the diagram from he low-pressure cylinder, with its M. E. P. augmented by the quotient of the product of the area and M. E. P. of the high-pressure cylinder divided by the area of the low-pressure cylinder, may be treated as an ordinary diagram; but the result by this method will be less than by the first.

When the two cylinders have different strokes as well as different piston areas, multiply together the M. E. P. piston area, and stroke of the high-pressure cylinder, and divide the product by the product of the piston area of the low-pressure cylinder multiplied by its stroke. The quotient will be the amount to augment the M. E. P. of the high-pressure cylinder before treating it as a simple diagram.

The same calculations may be more conveniently made by means of the following table; to use it, proceed according to the following rule:

Find under P the number which corresponds nearest to the terminal pressure of the diagram, and multiply the terminal pressure by the number opposite it to the right under W, and divide the product *by the M. E. P.*; the quotient will be the rate of *water consumption in lbs.* per 1 horse-power per hour.

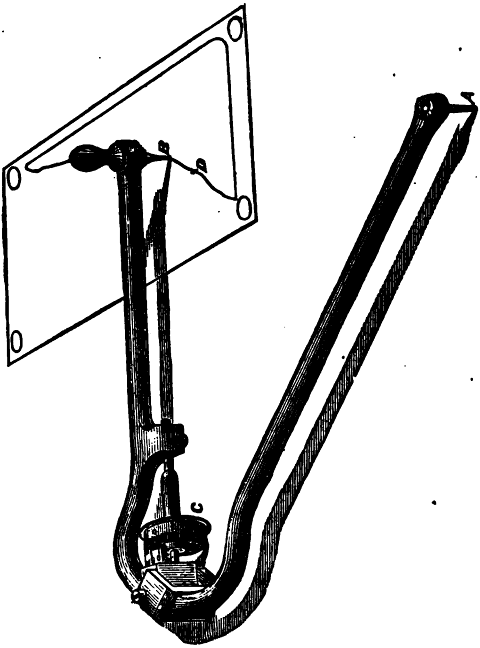
P.	W.	P.	W.	P.	W.	P.	W.	P.	W.
5	37·95	27	34·37	49	33·18	71	32·46	93	31·96
6	37·54	28	34·29	50	33·14	72	32·43	94	31·94
7	37·22	29	34·22	51	33·10	73	32·40	95	31·92
8	36·93	30	34·15	52	33·06	74	32·38	96	31·90
9	36·67	31	34·08	53	33·02	75	32·36	97	31·88
10	36·44	32	34·01	54	32·98	76	32·34	98	31·86
11	36·24	33	33·95	55	32·94	77	32·32	99	31·84
12	36·06	34	33·89	56	32·91	78	32·30	100	31·82
13	35·89	35	33·83	57	32·88	79	32·28	101	31·80
14	35·73	36	33·77	58	32·85	80	32·26	102	31·78
15	35·59	37	33·72	59	32·82	81	32·23	103	31·77
16	35·46	38	33·67	60	32·79	82	32·20	104	31·75
17	35·34	39	33·62	61	32·76	83	32·18	105	31·73
18	35·22	40	33·57	62	32·73	84	32·16	106	31·71
19	35·10	41	33·52	63	32·70	85	32·14	107	31·69
20	34·99	42	33·47	64	32·67	86	32·12	108	31·67
21	34·89	43	33·42	65	32·64	87	32·09	109	31·65
22	34·79	44	33·38	66	32·61	88	32·07	110	31·63
23	34·70	45	33·34	67	32·58	89	32·05	111	31·61
24	34·61	46	33·30	68	32·55	90	32·03	112	31·59
25	34·53	47	33·26	69	32·52	91	32·00	113	31·57
26	34·45	48	33·22	70	32·49	92	31·98	114	31·55

Example from same diagram. The terminal pressure is 25·5 lbs., and the mean of the numbers under *W*, opposite to 25 and 26 (34·50 and 34·41), is 34·45. The mean effective pressure being 30·5, the operation is as follows: 25·5 × 34·45 ÷ 30·5 = 28·8 lbs. per horse-power per hour.

As a matter of course, the theoretical rule of water consumption, as deduced from indicator diagrams, can never be fully realized in practice. It can only be approximated.

The Planimeter.

The Planimeter is an instrument by which the area of irregular surfaces may be accurately measured. The original instrument, which was invented by Amsler, consisted of two arms hinged *together* as shown, the other ends being the one fixed as at *A* in *the diagram*, the other *B*, movable. The arm with the movab rries a roller wheel, *C*, which is graduated and which by its n measures the area of the diagram traced out by the le end *B*. The theory of the apparatus is rather complex nnot be explained without the aid of the higher mathemat- t its use in connection with the measurement of the area of ;or diagrams is extremely simple.



use the instrument, fasten the figure to be measured on a ι board, and insert the point, *A*, in the board at any con- t location; then make a mark on the diagram, as at *D*; x the movable point, *B*, at the place selected for starting; urn the index-roller, *C*, round until O, on its periphery, *onds with the O on the* fixed vernier; then move it round the figure to the right, or in the direction of the hands of a wa After it passes round the entire figure, note how many wl numbers and subdivisions have passed the *O* on the vernier. whole numbers will indicate the square inches, and the subdivis tenths of square inches. If the *O* on the vernier falls betv two subdivisions marked on the roller, read the number of sq inches and tenths; then look on the vernier from *O* to 10, and a mark which coincides with one on the rollers; the numbe such mark, counting from *O*, will be the hundredths or se decimal place.

Thus suppose that, in the figure measured, six subdivisions part of another one have passed, and that the fourth mark or vernier coincides with a mark on the roller, the area of the fi will be either 3·64, 13·64, or 23·64 square inches, accordin whether the roller has made less than one, more than one, less than two, or between two and three revolutions. The can readily decide as to the number of revolutions the roller made, as it would be impossible to make a mistake of ten sq inches in estimating the area of a figure within the capacit the instrument. If the figure measured is an indicator diag it will nearly always be of less area than ten square inches, c most only a trifle more, as the utmost capacity of the indicat 5½ by 2¾ inches, or 15⅛ square inches; and they are very sel worked beyond 4 by 2½ inches.

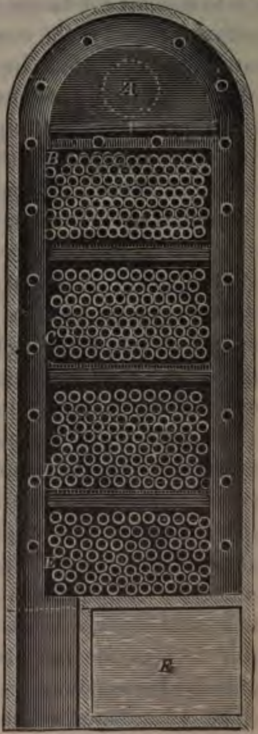
The area of a figure may be taken without placing the *C* the roller opposite the *O* on the vernier; but in such cases : necessary to take the reading before and after the tracing is m the difference between the two readings will be the area of figure. But it is preferable to place the *O*'s together. The n able point of the instrument may also be turned to the left, in this case the reading must be subtracted from 10 to give true reading. Each of the figures stamped on the roller indic a square inch of area, and if a figure contains 10 square in *at the tracing*-point, the roller will revolve once, and the *O*'s *coincide* as at the start.

CHAPTER XXIII.

CONDENSERS.

he object of using a condenser in connection with a steam
ne is to remove the back pressure, or a large portion of it,
to the atmosphere, by condensing
exhaust steam and thus producing
rtial vacuum on that side of the
n which is open to the exhaust.
a very necessary adjunct of the
pressure engine, and its use in that
ection, as well as with the low-
sure cylinders of multiple expan-
engines, is the main source of econ-
in engines of this class. The con-
er was invented by James Watt,
used it in connection with the first
n engines.

he two kinds of condensers in gen-
use are known as the jet and sur-
. The surface condenser consists
n iron box, in which brass or copper
s are inserted in tube sheets, simi-
to those of a tubular steam-boiler,
ugh which the water is forced by
circulating pump, for the purpose
ndensing the steam. In some cases
lensation is effected by bringing the
ust steam in contact with the out-
of the tubes, the circulating water
g on the inside; while in others the
n is *exhausted into the* tubes, and the circulating water
buted on the outside of them. There is no especial ad-



End View of a Surface Condenser with the Bonnet removed.

A snifting-valve is fixed on the condenser to allow the air an water to escape when the condenser is blown through. The va uum in the condenser keeps it closed, and, in the event of a gre head of water, or pressure in the condenser, the valve will ea up and allow it to escape.

TABLE

SHOWING THE FORCE WITH WHICH THE UNCONDENSED STEAM ARISI FROM THE WATER IN THE CONDENSER RESISTS THE ASCENT OR DESCE OF THE PISTON, ACCORDING TO ITS TEMPERATURE.

Temperature, Fahrenheit.	Force in Inches of Mercury.	Pounds per Square Inch.	Temperature, Fahrenheit.	Force in Inches of Mercury.	Pounds per Square Inch.
32	0·200	0·100	130	4·36	2·17
40	0·250	0·128	135	5·07	2·52
50	0·360	0·181	140	5·77	2·88
55	0·416	0·215	145	6·60	3·28
60	0·516	0·260	150	7·53	3·74
65	0·630	0·311	155	8·50	4·22
70	0·726	0·361	160	9·60	4·76
75	0·860	0·428	165	10·80	5·37
80	1·01	0·505	170	12·05	6·04
85	1·17	0·585	175	13·55	6·75
90	1·36	0·680	180	15·16	7·58
95	1·58	0·805	185	16·90	8·47
100	1·86	0·900	190	19·00	9·50
105	2·10	1·07	195	21·10	10·58
110	2·53	1·26	200	23·60	11·81
115	2·82	1·43	205	25·90	13·01
120	3·30	1·50	210	28·88	14·43
125	3·83	1·902	212	30·	15·

The temperature of the water in the hot wells of surface-con densing engines is generally about 100° to 110° Fah. A higher temperature would affect the vacuum and injure the air-pu lves, while a lower temperature would cool the cylinder, and use a waste of fuel by the condensation of the steam. A very w temperature causes increased consumption of fuel, while a very gh one causes a loss of power, owing to the back pressure inuced by the uncondensed vapor in the condenser, which will be own by the vacuum-gauge.

In the jet condenser, when the bilge-injection is opened, the air-mp draws off the air from the pipe, when the air in the ship, essing on the surface of the bilge-water, forces it up the pipe to the condenser. In the surface condenser the circulating mp creates the vacuum, and the air presses the water up.

In a jet condenser, if the injection-water is not shut off when e engines are stopped, the condenser will be filled with water, d, if not cleared before the engine is started, may cause serious amage to the cylinder or condenser.

Relative Quantity of Injection-Water Required to Condense a Certain Volume of Steam.

The weight or quantity of injection- or condensing-water reuired for a given weight or volume of steam depends upon everal conditions: 1. The pressure at which the steam is exausted. 2. The absolute pressure existing in the condenser after e vacuum has been formed. 3. The temperature at which the jection-water enters the condenser. While the first and second onditions vary but slightly with uniform load and steam pressure, he third will vary with the season, and even with the weather; onsequently, more condensing-water is required in summer than n winter. But the average amount may be illustrated as ollows:

Example.—Suppose the pressure in the cylinder at release or xhaust be 5 lbs. above atmosphere, and the absolute pressure in he condenser, after vacuum is formed, be 2 lbs., corresponding to vacuum of 26 inches of mercury. Each pound of steam exusted at 5 lbs. above atmosphere contains 1183 thermal units and the thermal units per pound of condensation at 2 lbs. lute pressure in the condenser are 126. Hence the thermal to be absorbed by the condensing-water are 1183 — 126 = Suppose the temperature of the injection-water be 80° Fah., each pound of condensing-water takes up 126 — 80 = 46 th units; and pounds of condensing-water per pound of stean densed become $\frac{1057}{46} = 23$ nearly. Suppose, again, that thi perature of the injection-water be 40° Fah., then each pou condensing-water takes up 126 — 40 = 86 thermal unit pounds of condensing-water per lb. of steam condense $\frac{1057}{86} = 12{\cdot}3$ lbs., from which it will be seen that the averag portion of condensing-water to the water of condensation is as 18 to 1.

The Vacuum.

If the cylinder of a steam-engine be filled with vapor, it be said to be void of matter; but if the vapor is condense the water from which it was vaporized drawn off, there wou created in the cylinder what is termed a "vacuum," or void The absolute pressure of steam is measured from zero, or p vacuum, and consists of the pressure indicated by the steam- (which is known as pressure above atmosphere), added t pressure of the atmosphere, as shown by the barometer. latter is, for all practical purposes, a constant quantity fo given locality,* and may be roughly taken at 14·5 lbs. responding to 29·50 inches of mercury. Vacuum-gauge usually graduated to agree with the scale of the baromete the vacuum is usually stated in inches of mercury. To the s pressure, as indicated by the gauge, add 14·5 lbs. for total *ure.* Thus, if the pressure by gauge is 60 lbs., the total pre

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* See Table on page 118.

4·5 lbs. Consequently, the total pressure on the steam side, at point in the stroke of the piston, is the pressure above the osphere plus 14·5 lbs., and the total pressure for the whole ie is the mean-pressure above the atmosphere plus 14·5 lbs. s, if the mean-pressure for whole stroke is 30 lbs., the total n-pressure is 44·5 lbs.; and this 44·5 lbs., whether the engine ndensing or non-condensing, is the variable factor in estima- the load on the engine. Now, if the engine be non-conden- the 14·5 lbs. (pressure of the atmosphere) on the steam side e piston is balanced by an equal atmospheric pressure on the ust side, and its effect is neutralized; but if the engine be ensing, a large proportion of the pressure of the atmosphere ie exhaust side of the piston is removed, and an equivalent on of the pressure of the atmosphere on the steam side of the n made to do useful work. With well-proportioned conden- apparatus, the pressure of the atmosphere on the exhaust side ie piston can be reduced nearly 90 per cent.

TABLE

ING VACUUM IN INCHES OF MERCURY AND POUNDS PRESSURE PER SQUARE INCH.

MERCURY.	POUNDS.	MERCURY.	POUNDS.
2·037	1	16·300	8
4·074	2	18·337	9
6·111	3	20·374	10
8·148	4	22·411	11
10·189	5	24·448	12
12·226	6	26·485	13
14·263	7	28·552	14

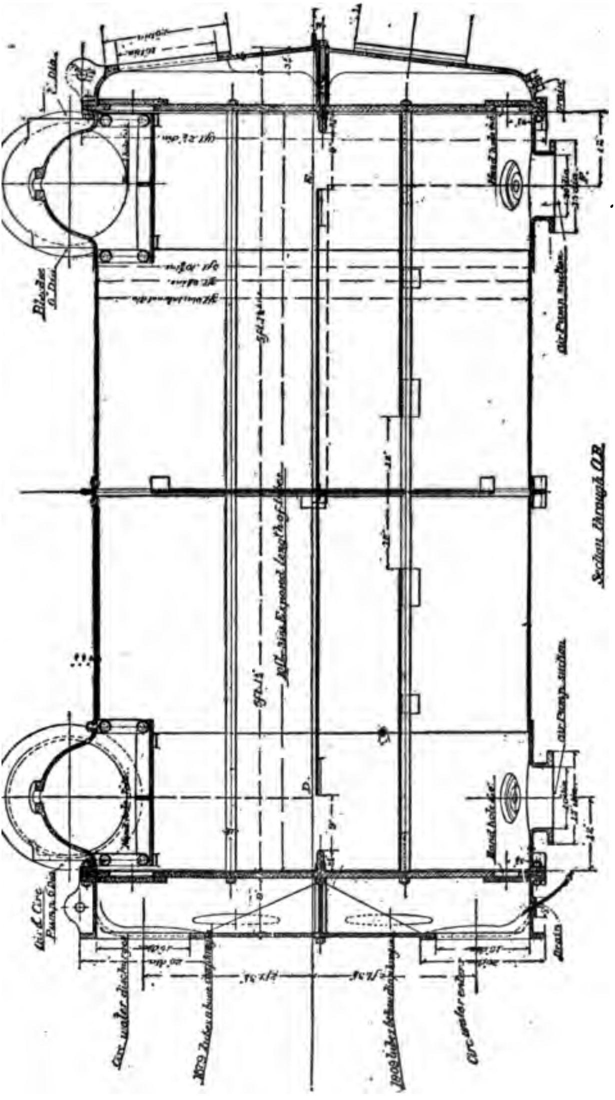
he lower the temperature of the water leaving the condenser, etter the vacuum, and the more conducive to power, always *osing there be no air-leaks.* Watt found a temperature of *in the water leaving the* condenser more beneficial than 70°

or 80°, supposing there be an abundant supply of cold water. It may be explained in this way. A better vacuum due to a temperature of 70° or 80° requires so much cold water in the condenser, (which must afterwards be pumped out against the pressure of the atmosphere,) that the gain in the vacuum does not equal the loss of power caused by the additional load on the pump. There is, therefore, a clear loss by the reduction of the temperature below 100°, if such reduction be caused by the admission of an additional quantity of water.

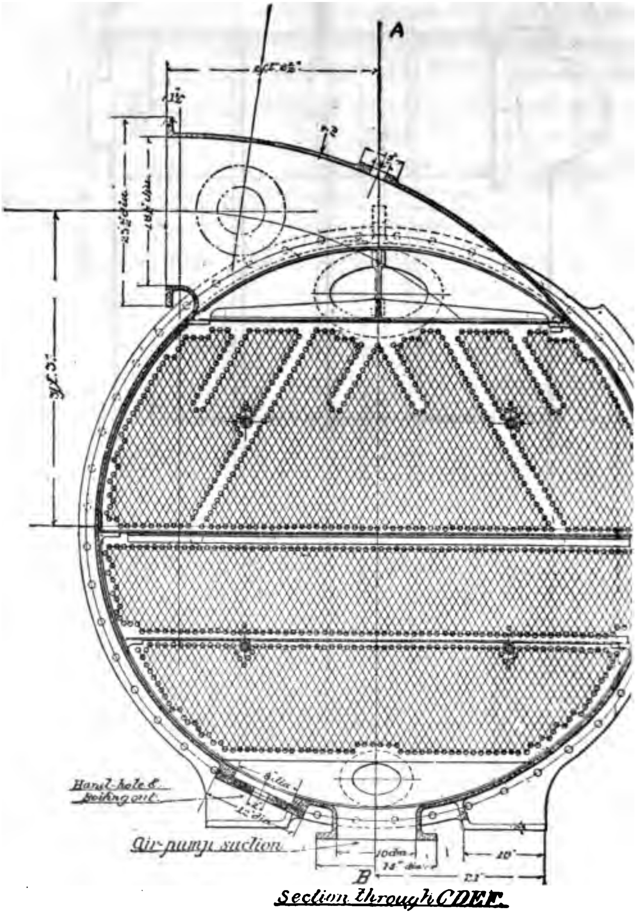
To produce a vacuum in a jet condenser, open the blow-through valve, when the steam, in its passage through, will blow out all air and water in the condenser; and as soon as the steam issues from the snifting-valve the blow-through valve may be shut, and the injection-cocks opened, when the cold water mixing with the steam forms a vacuum. When the gauge shows a sufficient vacuum, shut the injection-cocks, in order to prevent the condenser from being flooded.

To produce a vacuum in a surface condenser, open the injection-valve shortly before starting the engine, so that the circulating-water may enter the condenser tubes, and cool them. Then, when the engine is started, the exhaust steam comes in contact with the cooling surface of the tubes, and is condensed when a vacuum is formed.

The state of the vacuum is shown by the vacuum-gauge attached to the condenser; and, if it be imperfect, the cause must be ascertained and the fault corrected. If the water in the hot well be above the ordinary temperature, more injection water must be admitted; and, if the vacuum continues imperfect, the cause may be due to an air-leak in the valve or cylinder-cover, or in the joint of the eduction pipe. The door of the condenser should also be examined. The joints of the condenser may be tested by holding a candle to them, the flame of which will be drawn in if the *joints* are leaky.



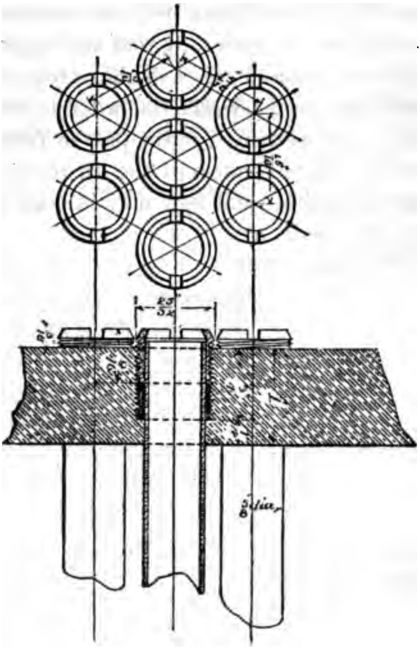
e Condenser for Coast-Line Battleships. Long



Surface Condenser for Coast-Line Battleships. T
verse Section.

Surface Condensers.

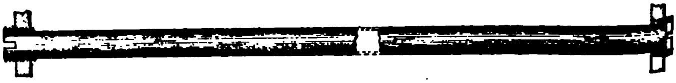
For marine engines surface condensers are used almost
clusively. The cuts on pp. 577, 578 represent longitudinal
d transverse sections of the type of condenser much used
the United States Navy. The condenser illustrated represents
e one used on coast-line battleships Nos. 1, 2, and 3, the auxil-
y boiler and the triple-expansion engines for which have been
ustrated and described
ove. There is a sepa-
e condenser for each
gine, made with cast-
ss heads and rolled-
ss shell, bolted and
etted together. The
tings are $\frac{7}{16}''$ thick
l contain all the noz-
s for steam and water
nings. The shell is $\frac{1}{4}''$
ck, bolted, strapped,
etted, and soldered
ether. The diameter
5 feet 9 inches and
length between tube
ets 10 feet 3 inches.
ch condenser contains
38 seamless drawn
ss tubes, $\frac{5}{8}''$ outside
meter, giving an out-
e cooling surface of
3 square feet. The
thod of securing and spacing the tubes in the tube sheets is
strated in the accompanying cut. As will be observed, the
e *sheet is 1″ thick* and drilled to take the tubes. The holes
then reamed out to a diameter of $\frac{25}{32}''$ for a distance of $\frac{3}{4}''$ from



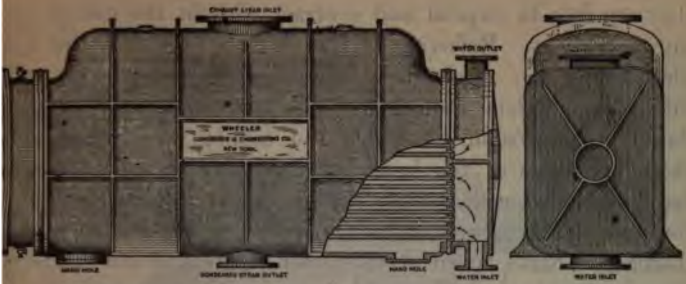
Method of Securing Tubes.

the outside of the sheet and tapped, after which a suitable packing is inserted around the tube and a brass ferrule screwed in t force the packing against the tubes. The tubes are spaced ¼″ centre to centre. The condensing water is taken from the sea or bilge by a separate centrifugal circulating pump for each condenser. These pumps are each capable of discharging 9000 gallons per minute. The air pumps for each engine are two vertical single-acting lifting pumps, having cylinders 20″ diameter and 18″ stroke, and instead of attaching the pump rods directly to the engines they are connected together through spur-gearing so proportioned that the engine will make two and one-half revolutions for each double stroke of the pump. This arrangement has been adopted in order to obviate the difficulty which has been experienced in the past in running these engines at a low speed. The cylinders of the air-pump engines are 6″ diameter and 12″ stroke, and they may exhaust either into the receivers or into the condenser.

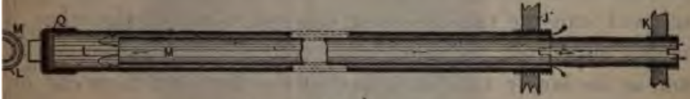
The same type may be used for stationary engines, although when used for this purpose the design is usually somewhat different. The cuts on p. 581 represent two different types of Wheeler condensers, the one a "single tube" and the other a "double tube" condenser. Referring to the former, it will be seen that its design is similar to that illustrated on page 568. The method of securing the tubes, which is shown in the accompanying cut, is somewhat different from the ordinary. At one end the tube is screwed direct into the tube sheet, its thickness at that end being somewhat greater, so that cutting the thread will not weaken the tube. The other end is secured by means of packing and ferrule, the same as in the marine-engine condenser described ove. In the double tube system the tubes are so arranged that



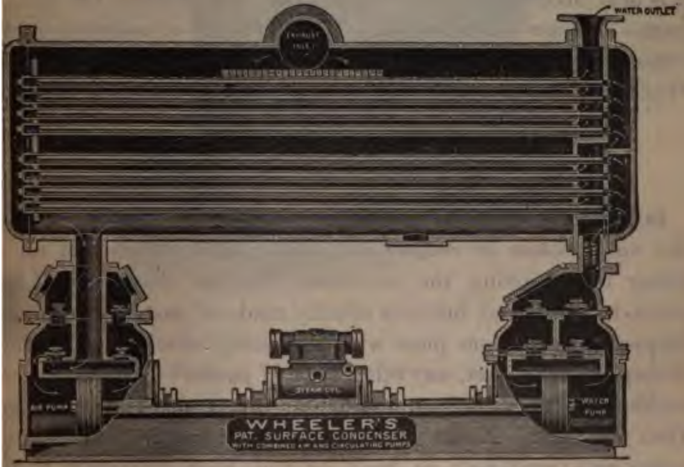
Wheeler Single Tube System.



Wheeler Surface Condenser. Single Tube System.



Wheeler Double Tube System.

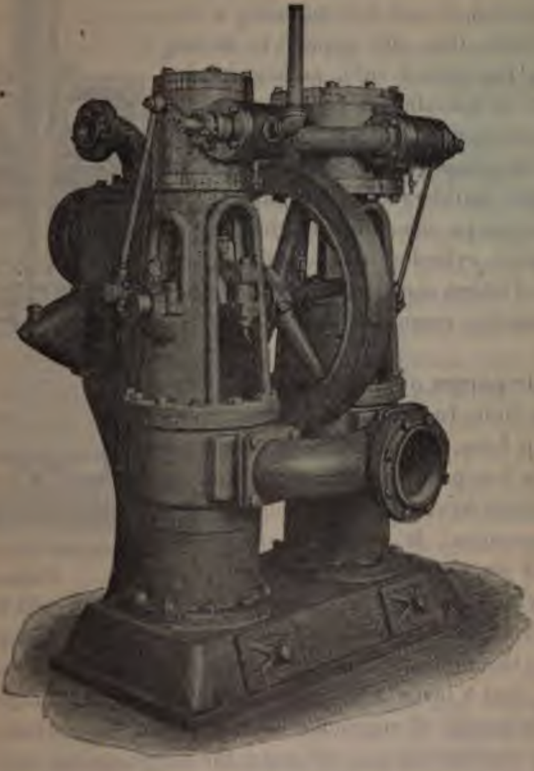


Wheeler *Surface Condenser.* Double Tube System (pumps attached).

they are free to expand and contract without the use of pac ing or ferrules. Referring to the cuts on page 581, the upp view shows the single tube system, with water and ste inlets and outlets indicated. The two other cuts show t double tube system, in which the cooling water first ent the inner tubes of the lower set, returning through the ann lar space between the tubes; then enters the upper chamber, f lowing a similar course in the upper set; finally escaping by t discharge nozzle shown at the upper right-hand end of the co denser. By the use of a double set of tubes, the one enclosed the other, the ferrules and packing are dispensed with. As w be seen in the enlarged view of a pair of tubes, the outer tube screwed into the tube sheet at one end, while at the other it merely supported, the same being true for the small inner tu and as the larger tube is capped at the free end, there can be leakage there, while at the same time the whole system of tu has ample room for expansion and contraction. To remove a tu it is only necessary to remove the head and unscrew the tube means of a screw-driver tool. The tubes are of seamless dra brass, tinned inside and out. These condensers are made by t Wheeler Condenser and Engineering Company of New York.

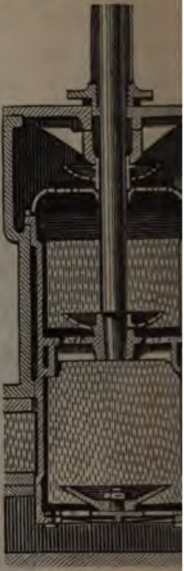
Jet Condensers and Air Pumps.

In the jet condenser all that is necessary is a vessel in whi the water comes in contact with the exhaust steam and an pump for removing the contents. Various shapes have be given to this vessel, but it is usually made of cast iron and it frequently cast in one piece with the pump, which may be sing or duplex, or, in fact, any other type of pump. Nearly all pu builders make some combination of air pump and conden That illustrated in the following cut represents a twin patte pump and condenser as built by the Barr Pumping Engi many of Philadelphia for engines of 60 to 4000 horse-pow



Barr Twin Pattern Vertical Air Pump and Condenser.

All condensing engines have of necessity to be provided an air-pump, for the purpose of extracting the air, injec water, and the water of condensation from the condenser, in order to maintain a vacuum. There does not appear to be any uniform, recognized rule, among marine engineers or manufacturers of surface-condensing compound engines, for proportioning the air-pumps to the steam-cylinder, as, while some builders make the capacity of their air-pumps one-eighth of that of the low-pressure cylinder, others make it one-tenth, and others one-eleventh; the average of the number examined being about one-ninth.


Section of a Mari
Pump.

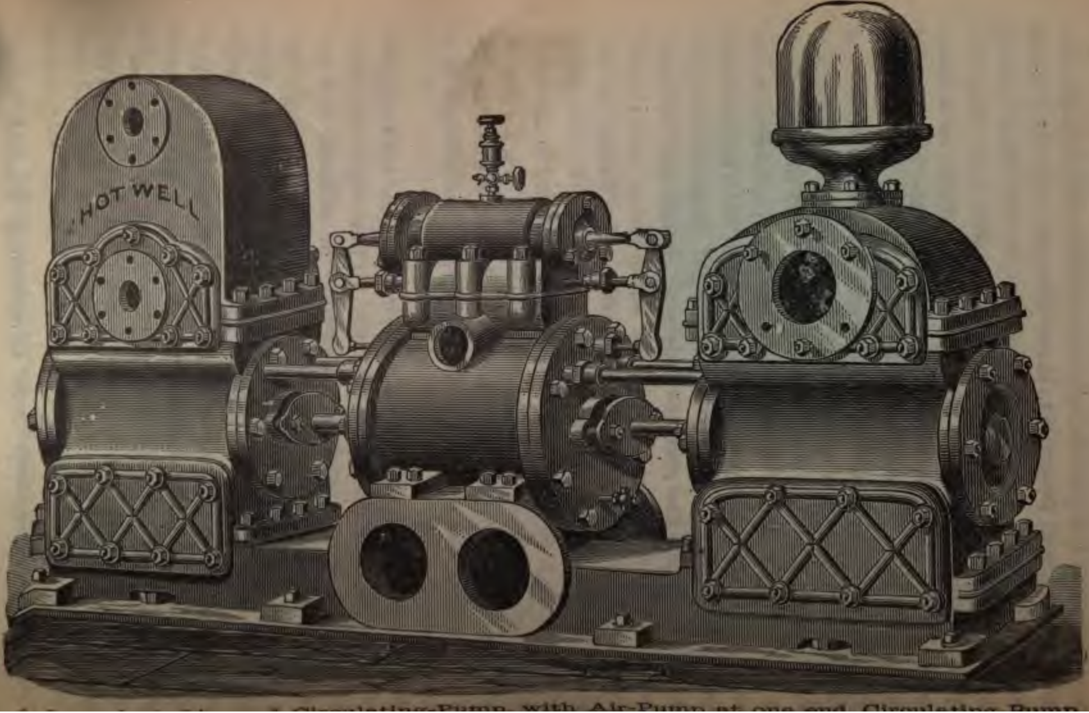
The air-pumps of the steamships Pennsylvania, Ohio, Indiana, and Illinois, of the American Line, are one-eleventh the capacity of the low-pressure cylinder. And, as these engines have the reputation of being very economical, it should be presumed that their proportions are good; nevertheless, they are evidently too large, as one-fifteenth would be to a correct proportion. The tendency among marine engin to overdo the thing in the case of air-pumps, perhaps under t pression that a large air-pump creates a better vacuum, an result, air-pumps of enormous diameter and long stroke a tached to marine engines; whereas, the air-pump has very li do with the vacuum, its functions being simply to clear th denser of water and air. Any proportion that will accomplis will fulfil all the necessary requirements. An air-pump too for the purpose for which it is intended, can have no other than to absorb much of the power which might be utilized creasing the speed of the engine and economizing the fuel. T *pump piston*, being resisted by the pressure of the atmospher

rom four to five per cent. of the power of ordinary simple con-
g engines, and from two to three per cent. in the better class
pound marine engines; the power required to work it being
st when the vacuum is most perfect, and least when the
m is impaired. A good deal also depends on the mechanical
gement employed to work it, as well as on the condition of
kings, bearings, proportions, etc.

capacity of the air-pumps of condensing engines using a
spray, ranges from one-fifteenth to one-twentieth the capac-
the cylinder. As it requires from 22 to 30 times as much
to condense steam as there is water in it (according to the
re and temperature), the air-pumps ought to be proportioned
et the maximum demands. The right proportions of air-
s for both jet- and surface-condensing engines may be found
culating the displacement of the steam-piston, and that of
ir-pump for one minute, and *dividing* the former by the
. The use of the air-pump in connection with condensing
es, as before stated, is not an absolute necessity in all cases,
th a head of water having a fall of about 13 feet, a vacuum
e formed and maintained in the condenser without an air-
, providing the end of the delivery-pipe is submerged in a
of water.

rtical air-pumps, with valves in their pistons or buckets, give
est satisfaction, as, in that case, the air and vapor are lifted
orced out of the condenser, relieving the exhaust and in-
ing the vacuum. The capacity of the openings through the
-seats of air-pumps should be such that the maximum flow
e water through them will not exceed 10 feet per second.
nstance, suppose a pump of 12 ins. stroke to make 50 strokes
inute, the maximum travel of the bucket at midstroke will
out 2·6 feet per second. Then, as 10 ÷ 2·6 = 3·84, the capac-
the opening should not be less than one-fourth the area of
umps.

r-pumps *are frequently* very injudiciously located, being



[illegible] Circulating-Pump, with Air-Pump at one end, Circulating-Pump ondenser; whereas, if placed below it, their re be fewer, as the water would fall by gravity er into the air-pump. In some cases the air- n through the condenser, so that the openings vel with the bottom of the condenser, which is nt in every respect, except that it necessitates a has a tendency to absorb power.

r-pumps, a cut of which may be seen on page ir-cylinder at one end, the circulating-water cyl- and the steam-cylinder in the middle, are being opted on ocean steamers. The claim set up for hey are independent of the engine, they can be slower, according to the circumstances of the sorb none of the power of the engine, and are to accident in stormy weather, or whenever the air-pumps attached to the main engine; that and a vacuum formed, before the engine com- t the injection-water can be more easily reg- quire no expensive foundation; that, in con- r- and air-pistons being on each end of the ve a more steady and uniform motion than has, and that, in consequence of all their they can be easily examined, and any de- r readjusted, without interfering with the

sing engine, the air-pump has only to ex- g from the condensed steam and the uncon- condenser. In a jet-condensing engine, ithdraw both the injection-water and the the work to be performed by the latter es greater than that of the former.

mes fitted to a circulating, reciprocating, or the purpose of admitting air to the water on the up stroke. As the valve is closed against the dow stroke, the air admitted serves to soften the shock of the water.

A bucket air-pump is a single-acting pump, being, in fact, piston with a valve fitted to it, which closes on the up stroke an opens on the down, lifting a quantity of water equal to its capacit at each stroke of the engine.

A piston air-pump is a double-acting pump, the piston bein solid. It is fitted with suction- and delivery-valves, and di charges with each stroke.

A plunger air-pump is a double-acting pump, resembling th bucket air-pump, except that it has no head-valves, and that th bucket-rod is fitted with a plunger. The effect of this is, that th plunger, owing to its displacement, discharges on both the up an the down stroke.

The double-acting air-pump has both suction- and deliver valves; but it is possible with the single-acting pump, in som cases, to dispense with either the one or the other. They a generally made with pistons, though sometimes with plungers.

An air-pump with a foot-valve and no discharge-valve woul be most affected by a leaky stuffing-box; and, while the foot-val remains, the pump will draw water, but if removed, it will fail t work.

An air-pump trunk is a hollow cylinder attached to the buck or piston, and working through a stuffing-box. Such an arrang ment is rendered necessary when the pump is worked directly o the crank-shaft, or where it is located so close to the leve through which the motion is transmitted from the engine, as t render the appliance of an intervening cross-head and links im possible. The difference in the discharge is equal to the relativ *difference* between the displacement caused by an ordinary ai *mp rod* and that caused by the trunk.

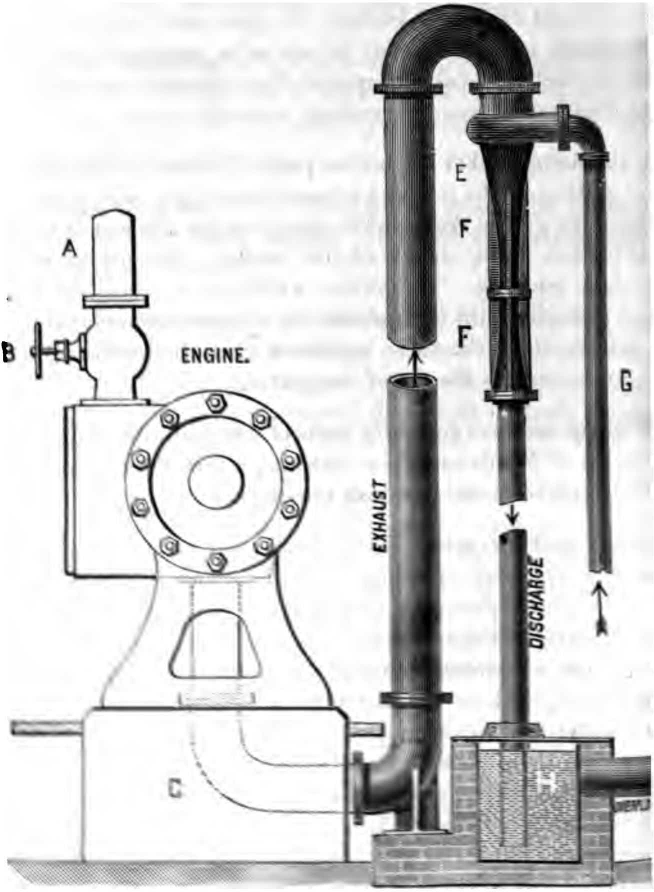
ir-pump pet cock or valve is generally placed below the ve and above the bucket. It opens with the down stroke ›ump, and admits air to act as a cushion on the water. he delivery-valve is opened, the engineer can tell by its hether the pump is working properly or not.

-pump bucket is a hollow piston, generally made of brass, rating in the top, and a boss (water-tight) which receives in its centre, from which strengthening ribs run to the rim ucket. The outside of the bucket is grooved to receive ;ht packing. The valves, which are generally of India-and whose lift is regulated by a guard secured by a nut, inst which the valve is pressed when the bucket is on the oke, are on the top of the grating.

ump rods are generally made of wrought-iron, and covered kin of Muntz metal, or brass, to prevent the oxidization to rought- or cast-iron rods are exposed.

p's side air-pump discharge-valve is generally a mitred ith its spindle passing through a gland in the cover, on weight is placed to keep it shut. It differs from a stop-having a lift and weight.

are numerous contrivances in use for dispensing with pump, such as the injector condenser, which produces a water in the exhaust-pipe; but the necessary arrangements ating them generally cost more than a good reliable air-hough the first cost of the former is less than that of the Besides, the vacuum is never so perfect when produced by h arrangement as when created by a close condenser and p. This becomes obvious, since we know that, even with t perfect mechanism, it is almost impossible to attain a vacuum, and maintain it for any length of time, as nature a vacuum, as the atmosphere on the outside of a vessel antly *endeavoring to* equalize any unbalanced pressure *exist on the inside.*



The Injector Condenser.

A shows [illegible] B [illegible] position; C the exhaust-pipe; E annular [illegible] condensing-water is thrown through many [illegible] which the water is formed int [illegible] nozzles through which the condens [illegible] H

The Injector Condenser.

The cut on the opposite page represents the injector condenser, so lled because its action is similar to that of the Giffard boiler feed- jector. It consists of two conoidal nozzles, joined by a straight ck. and swelled at the upper end for the junction of the water- zzle. Within is the exhaust-steam nozzle, which forms within condenser a narrow, annular space for the entrance of the con- sing-water. The sides of the condenser (which are parab- idal curves) are smoothly finished, as is the contracted neck ow, to diminish the resistance of the water. When used in nection with a condensing engine, the air-pump may be dis- sed with, as steam of atmospheric pressure will flow into a uum at the rate of 1600 feet per second.

Vhen the exhaust steam from the engine meets the thin film water which enters by the annular space, it is instantly con- sed. As the water passes down, the contracting outline of the denser gradually brings it to a solid jet in the neck below, ough which it rushes with a velocity due to its pressure. The which has entered the condenser with the water, or through y joints or stuffing-boxes, together with the uncondensed or, is thus drawn down into a contracting, hollow cone of er, until finally expelled through the neck. This latter being ight for a distance, is virtually the air-pump, having a solid on of water moving at a high speed; thus is the steam con- sed, and the vacuum formed by a single process, and with ater certainty than in any other way. The air and vapor ing passed the contracted neck, enter the tapering nozzle ow, and expanding therein are prevented from returning to condenser above.

The method of operation of the injector condenser when the en- e is started is as follows: the exhaust steam expels the air from exhaust-pipe and condenser; then a jet of cold water from a *mp or tank creates a vacuum*, which may be maintained by a *d of water of 10 feet fall.* The discharge-water passes a temperature of 110° to 112°, when the vacuum is equal tc inches of mercury.

The advantages of the injector condenser are, that it is ch light, simple, and durable; that the injection-water is self-r lating; that there is no possibility of the water being carried into the cylinder; that, simply by the removal of a bonnet, exhaust steam may be allowed to escape into the atmosphere, t converting the engine from low to high pressure; that the denser requires no foundation or any other attachment save an dinary pump to raise the water when there is not sufficient f and that the condenser can be attached to any engine in any cality where the necessary supply of water can be obtained, wh ranges from 22 to 25 times as much as that from which the st would be generated. It is claimed that a saving of over 20 cent. may be made where these condensers are used, while the f cost is trifling.

QUESTIONS.

What are the functions of the steam-engine indicator?

How would you proceed to attach the indicator?

State the conditions which are instrumental in determining conformation of a diagram.

Explain the points of difference between diagrams taken fi automatic cut-off engines and those taken from slide-valve th tling engines.

How would you draw the theoretical expansion curve geor rically?

How would you trace a theoretical compression curve?

From what circumstances does the inaccuracy of the theoreti curve arise?

Describe the adiabatic curve.

How would you locate the theoretical terminal pressure c responding to the actual cut-off?

Iow do you account for the difference in theoretical correctness hown by expansion curves of diagrams taken from different ines?

Vhy is the incorrectness of the expansion curve less with an ine heavily loaded than with a light load?

f the deviation of the expansion curve in diagrams (other ıgs being equal) be found to be greatest when the water is h in the boilers, and the steam rapidly generated, to what se might it be assigned?

Vhat is the most obvious lesson to be deduced from the facts ur possession in regard to the incorrectness of the curves of grams taken from large engines?

Vhat should be considered in indicator diagrams as indications good construction and performance?

Iow do you calculate the mean effective pressure?

Iow would you space the ordinates?

Iow do you calculate the indicated horse-power?

Iow do you calculate the theoretical consumption of water m indicator diagrams?

Iow do you make allowance for clearance and cushion?

Iow do you estimate the effect of compression?

What is the object of indicator diagrams?

What information do indicator diagrams supply?

Iow do indicator diagrams show the steam-pressure in the inder?

When the line representing the back pressure in the diagrams high-pressure engines shows more than one pound above atmo-ıere, or in low-pressure engines more than two or three pounds n the vacuum-gauge shows in the condenser, what does the gram indicate?

How does the diagram show whether the valves are properly or not?

How does the diagram show whether the piston and valves are king or not?

How does the diagram show whether the steam is throttled or not?

How does the diagram show the effect of small steam ports steam connections?

How does the diagram show the effect of exhaust lead?

How does the diagram show that the indicator is out of or

How does a diagram show the point of cut-off?

How does a diagram show the state of the vacuum in the denser, and whether too much injection-water is used or not?

Sketch a diagram, and explain it.

Show the points of excellence in a perfect diagram.

Show the steam, atmospheric, and vacuum lines and the ex sion and exhaust curves.

Define the adiabatic curve, and explain how it is obtained.

Define the asymptote lines.

Define the term compression.

Define the term cushion.

Define the term clearance.

Define the terms flexure and contrary flexure, and demons them on the diagram.

Define the term hyperbola, and illustrate it.

Give the meaning of the term isothermal.

Point out the ordinates on the diagram.

Define the term parallelism.

What is meant by the initial-pressure?

What is meant by the term mean effective pressure?

What is meant by the term terminal-pressure?

What is meant by the term scale in its application to diagram?

Explain the functions of the spring in its relations to indicator.

Explain the meaning of I. H. P., N. H. P., M. E. P., and B

Explain the meaning of the term string.

Define the term undulating.

What are the use and functions of the dynamometer?

What is the meaning of the letters *B* and *T* which are tly seen on diagrams?

Define the term zero when applied to indicator diagrams.

Give the formula for finding the horse-power of an engine from icator diagrams.

What are the functions of the planimeter?

Explain the most correct method of using the planimeter.

What is the exponent of the work performed by a steam-engine? r the meaning of the term mean effective pressure, see page 9.

What is the best criterion of the most economical results which team-engine is capable of producing?

What is the object of attaching a condenser to a steam-engine?

Give the names, and the advantages and disadvantages of the o kinds of condensers in most general use, with a description the same.

Explain how the injection-water enters and escapes from surface d jet condensers.

State what relative proportion the jet condenser should bear to e steam-cylinder of a condensing engine.

State what relative proportion the cooling surface in a surface ndenser should bear to the cubic contents of the steam-cylinder.

State the respective advantages and disadvantages of having ndensers too large or too small.

What is the most advantageous temperature at which to keep e water in hot wells? and what effect does too high or too low temperature exert on the economical working of the engine?

Explain the arrangements by which the bilge injection-water introduced into jet and surface condensers.

What would be the effect of not shutting off the injection-water hen the engine is stopped?

State the quantity of water necessary to condense steam, with formula.

Give the rule for finding the cooling surface in the tubes of rface condensers.

PART VII.

GAS AND GASOLINE ENGINES.

CHAPTER XXIV.

ALTHOUGH gas and gasoline engines are made up of parts ing a general similarity to those of the steam engine and with functions, they have one fundamental point of difference—nam in the medium whose expansive property is made use of to tr form heat energy into the kinetic energy of mechanical motion. the case of the steam engine heat energy is imparted to the v of water in another apparatus, the boiler, and the steam is bro into the engine and allowed to expand and do mechanical w In the gas engine it is air whose expansion is made use of. M over, the heating of the air is performed in the cylinder of engine itself, so that the gas engine takes the place of a st engine and boiler. The heating of the air is performed by ad ting into the cylinder a quantity of gas, gasoline, petroleu other inflammable oil, mixing it at the same time with air igniting the mixture at the proper moment. The intense produced raises the air to a high temperature. It there expands and pushes over the piston as does steam in the st engine. At the end of the stroke suitable valves open to a the exhaust of the products of combustion from the cylin and other valves in turn open to let in new charges of air fuel.

The fuels principally used are gas, either natural or artifi gasoline, and petroleum, the quantity per horse-power requi *depending* upon the quality of the fuel; that is, upon the n *ber of* heat units in each pound. With ordinary illumina he quantity per indicated horse-power per hour will vary 17 to 20 cubic feet. With Pittsburg natural gas it has as low as 11 cubic feet; using 74° gasoline, known as *stove ine*, the consumption per horse-power hour is about one-tenth e gallon. The amount of petroleum used would be about ame. By taking gas obtained from coal in a producer and uring the number of pounds of coal per horse-power hour re-d, it has been found that the gas engine exceeds the steam e and boiler considerably in economical use of coal, the tests rofessor H. W. Spangler, of the University of Pennsylvania, 100 horse-power gas engine showing that an indicated horse-r was produced with a consumption of about one pound of per hour. A producer plant and gas engine are much more nsive than a steam engine and boiler, so that the price of at any place will determine as to whether, on the whole, the f a gas engine is desirable.

he Otto Cycle.—Most steam engines are double-acting; that ke steam alternately at each end of the cylinder, although of them, like the Westinghouse and Willans, are single-g and take steam at only one end. Nearly all gas engines single-acting and, moreover, take in a charge of gas and air *second* revolution, instead of *every* revolution, as in the case ngle-acting steam engines. The complete cycle of operations hich nearly all gas engines operate is known as the Otto , and is as follows:

orward stroke.—Admission by suction into the cylinder of a charge consisting of air mixed with some combustible gas or vapor.

eturn stroke.—Compression of the charge. At the end of this stroke the charge is ignited.

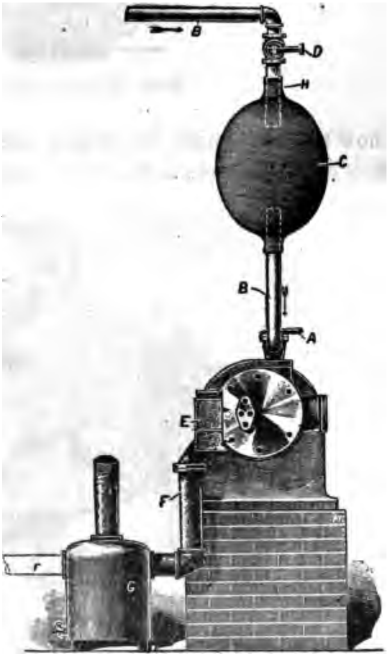
orward stroke.—Expansion of the charge which has been heated by combustion.

eturn stroke.—Expulsion through the exhaust openings of the mixed gases which have been cooled by expansion.

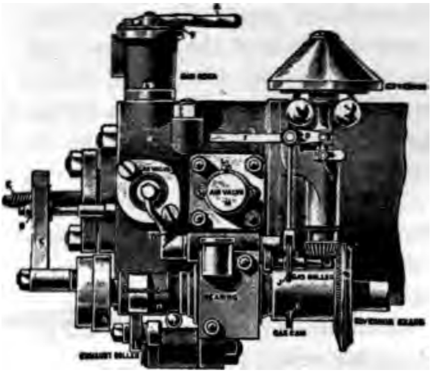
e temperature produced by rapid combustion of the ignited charge is very high, probably about 3000° F., so that it is n sary to cool the cylinder by means of a jacket supplied with ning water. Otherwise the packings would be destroyed, pr ture ignition would take place, and lubrication would be imp ble. The heat imparted to the water jacket is in general wa and amounts to about 40 per cent. of the total heat energy of gas. Were it not therefore for the necessity of cooling the cy der the efficiency of the gas engine would be much greater e than is now the case.

Methods of Igniting the Charge.—The earlier method of niting was by means of a flame produced by burning a jet of or vapor with which the ignited charge was brought into con at the proper moment. A great improvement was made by us instead of the flame, a tube kept red-hot by a flame of gas or va burning outside of the cylinder. Such devices are rather se tive to variations in the proportions of air to fuel and h largely given way to electric igniting devices. The first form these made use of a platinum strip heated white hot; but v found unsatisfactory, as the platinum had to be kept so near fusing-point, in order to produce certain ignition, that it was destroyed. At present electric igniters operate with a spark duced by breaking an electric circuit which has a current flo through it. They may be divided into two classes, *fixed-spark* and *break-spark gap.* In the former, two electrodes, insul from each other, are placed in the end of the cylinder at a tance from each other of a small fraction of an inch. The se dary circuit of an induction coil is connected to these electr In series with the battery and primary circuit of the induc coil is placed a contact operated by the engine, which makes cuit and promptly breaks it again just at the moment when i tion should take place. A spark passes across the gap betw the two electrodes and causes the gas to ignite. In the bre spark gap-igniter one electrode is fixed and the other moves s to come into contact with it at the proper time. A battery spark coil are connected in series with the two electrodes.

overning.—The speed of gas engines is generally regulated by ing off the supply of fuel partially or entirely when the num- of revolutions is too great. The regulating device usually ists of a ball governor of the Waters type (see page 409), h operates a suitable valve. Such a method is open to the dvantages of fly-ball governing which obtain with steam en- s. Further, it operates less quickly from the fact that gas is n in only once in four strokes in the normal running of the ne, whence it happens that a much longer time elapses between novement of the fly-balls and the changing of speed than is ase with steam engines. Although gas engines are provided exceedingly heavy fly- els, their variations in d are several per cent. ter than those of good n engines.

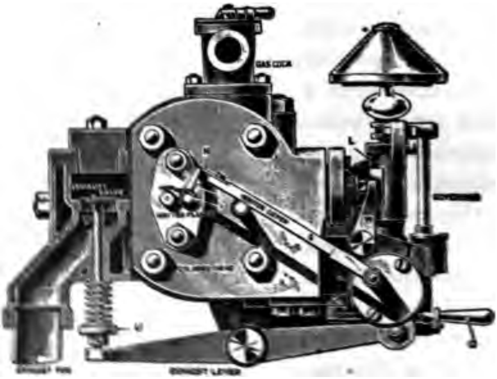


he Otto Engine, being earliest successful gas ne, and partially on account the one most ly used at the present has been chosen as a esentative for more par- ar description. In the cut, which shows a view ing at the rear end of cylinder, *B* is the gas uel supply-pipe; *D*, a e; *C*, a rubber bag, the ct of which is to dimin- fluctuations in the gas- sure; *A* is a valve cor- onding to the throttle e of *a steam engine; F* *exhaust pipe; and G* is a cast-iron pot which serves to deaden the noise of the exhaust. The second, third, and fourth



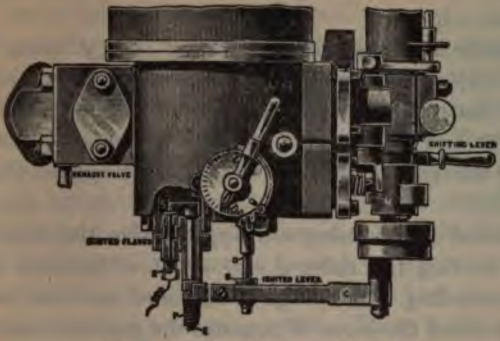
Side View of Cylinder End.

show the mechanism in greater detail. When the throttle *A* is open gas gets as far as the gas valve. This is opened



End View of Cylinder End.

proper time every second forward stroke by the lever-arm l a length of time which is controlled by the governor. Ai tted at the same time through the valve *M*, which is operated tomatically by suction produced by the advance of the piston.



Top View of Cylinder End.

the return stroke the air valve closes and the mixture of air and in the cylinder is compressed to a pressure of some 70 pounds

General View of Otto Engine.

r square inch. Just after the second forward stroke commences *ignition takes place.* The heated gaseous mixture expands, driving the piston before it till the end of the second forward stroke is reached. Then the exhaust valve is opened by the motion of the exhaust lever operated from a cam, *H*, which strikes the exhaust roller *I*.

The igniter is of the break-spark gap type, *R* being the fixed electrode and *S* the rocking lever-arm of the movable electrode *E*. The battery and spark coil are connected in series with each other and with the spark-gap. Contact is made and broken by the igniter lever *C*, which pushes against the movable electrode *E*.

The method of governing will appear from the second cut, the governor moving the roller *J* into or out of the path of the gas cam *K*, according as a charge is required or is to be omitted. When *J* is lifted the lever *W* actuates the gas valve and a charge of gas is admitted.

Management of Gas Engines.—As the gasoline engine is practically the same as a gas engine, with some slight changes in the admission valve, the following will apply in general to both engines. In addition to the ordinary precautions to be observed in running machinery, the following points must be complied with:

1. The gas or vapor must be admitted in the proper proportion to the amount of air. An excess of combustible is particularly to be avoided.
2. To obtain full power the entrance as well as the exhaust of air should be unchecked.
3. The inlet and exhaust valves should close tightly, the piston should be well packed, and all possible leaks should be guarded against.
4. The entire charge should be ignited and the ignition should occur at the proper time.
5. The cooling of the cylinder by means of the water jacket should be efficient.

These points will now be taken up more in detail.

Admission of Fuel.—In gas engines the fuel is gas admitted r a slight pressure. In gasoline engines the fuel is vapor of ine carried by air sucked in through a vaporizer containing asoline. In petroleum engines the fuel is sprayed into the n of air which enters the cylinder.

the case of gas engines the gas pipe near the engine is pro- with a rubber bag or receiver with rubber diaphragm. The rance of this flexible wall shows plainly, when the engine is ng, whether the head of gas keeps fairly uniform; that is, ier the supply is sufficient without being at times excessive.

e valve which regulates the admission of gas during the ssion of air to the cylinder should close tightly every time. does not, there is danger of having an excess or deficiency s admitted as the gas-pressure may rise and fall, especially engine is run at a varying speed. There is also danger of ng gas on light loads. An irregularly leaking valve is apt oduce puzzling behavior, as excessive and deficient charges e mixed promiscuously with proper ones. Any considerable s of gas will produce a smell and smokiness of the exhaust ll as a failure to ignite regularly.

deficiency of gas will produce slow combustion of the charge, impulses on the piston, and eventually weak or strong ex- ns in the passages through which the air is admitted. It also cause failure to ignite regularly.

after having found the gas valve to be tight, there exists loubt as to the admission of the proper amount of gas, an ator should be employed if one is available. If not, the tment may be made approximately by varying the quantity admitted until the best result seems to be obtained.

th those engines whose speed governor acts on the hit-or- plan—*i. e.*, which allow either a full opening of the gas valve cur or none at all—the accuracy of adjustment of the gas ssion can be determined as follows:

such a load on the engine that it will take several charges *cession, then cut off* one and then take several more. Then *the strength of* the individual impulses following each ignition. The first impulse succeeding a cut off should be sligh weaker than the succeeding ones. If it is notably weaker, th is a deficiency of gas. If it is as strong or even stronger th the succeeding ones, there is an excess of gas.

Admission and Exhaust of Air.—Air is as essential to t engine as the fuel. The more air is admitted the more fuel c be used, and (other things being equal) the more power the engi will develop.

The inlet valve should not only afford a sufficient opening, it should be properly timed so as not to shut off the entrance early or too late, as in the latter case a part of the charge is pelled after having been admitted into the cylinder. The cha is also apt to be reduced if there is an excessive back pressure the exhaust pipes, due to insufficient size, extreme length, accumulation of water from condensed moisture in a long pi

Leaks.—Any leaks by which the pressure is allowed to esc from the cylinder result in a reduction of power and a w of fuel. Leaks toward the water jacket or around the cylin are easy to detect. The exhaust valve is the part that is m likely to become leaky by reason of the high temperature which it is submitted. It is generally of the poppet type, w conical seat, and so disposed as to be easily inspected and regro to its seat with powdered emery and oil.

When the inlet valve leaks the result is more pronounced th for any other leak of the same magnitude, because the gases only leave the cylinder, but they accumulate in the space or sage through which the air and the fuel are admitted and sub ute themselves for pure air in each subsequent charge, thus bing the proper adjustment of air and fuel.

small leak toward the water jacket does not do much ha g as the engine is kept running at full power. At a redu specially on starting the engine, the entrance of wa r through the leak is likely to be much more d sible to use the engine temporarily in ing the water from the jacket just

›pping the engine, and by not refilling the jacket with water ıtil after having started it, and then keeping the engine always ıder a fairly full load.

All leaks should be remedied without delay, as otherwise they ll become worse in course of time.

Ignition.—Failure to ignite properly may be due to the charge ›t being of the proper composition, as pointed out previously, or a deficiency in the igniting device. The latter is almost always ;her a heated tube or an electric sparking device.

The tube is to be heated to a temperature ranging from red heat bright yellow, according to the nature of fuel and the construc›n of the engine. When once determined this temperature ould be maintained as nearly constant as possible. All leaks and above the tube should be avoided. If there is no timing lve between the cylinder and the igniting tube, the moment of nition depends entirely on the temperature. If it is too low, the nition will occur too late and even fail entirely part of the time, sulting in reduced power and waste of fuel. If the temperature too high, the ignition is premature, which also causes loss of ›wer and undue strain and wear of the engine. With some nds of natural gas even the highest temperatures that the tubes ill stand are not sufficient to give a good result.

Such an igniting device is particularly sensitive to irregularities the proportion between air and fuel and to the effects of leaks. there is a timing valve, the ignition is less sensitive to disturbg influences, but the timing valve itself must be kept in good ›ndition.

As previously stated, electric igniting devices may be divided to two classes, those with a permanent-spark gap and those using break spark. With the first class an electric pressure sufficient cause a spark to leap across the gap is produced by an induc›n coil. This pressure is considerable, and the insulation has to very perfect, otherwise the current will leak through any fective spot, instead of crossing the spark gap.

The insulation is generally impaired by moisture or by oil.

Near the points of the spark gap, inside of the space of cyl it may also be impaired by a deposit of carbon.

In order to detect quickly whether the apparatus is at f provide a special adjustable spark gap of greater length and c nect it in multiple with the spark gap in the cylinder. T adjust it to a length a little greater than the regular gap, so t the current will cross the one inside the cylinder in preference it, but only slightly so. If there is failure to ignite, disconnect wires leading to the regular spark gap, and if the longer spec gap shows a spark the generating apparatus is not at fault. Th having connected the regular igniter gap again, adjust the speci gap to such a length that the spark will cross it in preference the regular one when everything is in good working order. then no spark appears at this shorter special gap, it must be co cluded that the insulation about the regular gap or its connecti wires is defective. If a spark does appear, the failure to ig should be sought in the nature of the charge. If the engi is provided with a break-spark device, the electric tension is le than with a spark gap, and the insulation need not be so perfect. To test such a device, set the engine so that the contact is mad inside. Having previously disconnected the connection at one spot, make and break a contact there swiftly by the hands; a brigh spark should appear if the rest of the circuit, including the mak and break contact inside the cylinder, is in good order. If n good spark is obtained, revise all the contacts and renew the battery if need be. If there is failure to ignite while a good spark can be thus obtained, set the engine so that the contact inside i not made; then connect a piece of wire to one side of the igniting device, say the body of the engine, and touch with the other en of the wire the other (the insulated) side of the igniter. A brigh spark should be seen. If not, the insulation is at fault. When there is failure to ignite on starting the engine when cold look for moisture on the insulation of the igniter or on the spark gap *or contact* breaker. In very cold weather heat these parts previously. It is well to have two sets of cells always in readiness which can be thrown in by a switch. The circuit of the ıld be opened when the engine is stopped. In the break-p device the contact previous to the break must not be ıort duration. If there is no means of lengthening it, ıle can be compensated somewhat by the addition of more he breaking of contact should be as sudden as possible.

g the Cylinder.—The object of the cooling is to facilitate ɔn, to prevent premature ignition, and to preserve the . When running at full load there is never danger of oo much, but with a new engine the stream of water .ot be turned on too suddenly if the engine has been ,o become rather hot by neglect, as this contracts the cyl-ore the piston has had time to contract also. In connect-|acket with a circulating tank be careful to avoid air n the pipes. On stopping the engine for a long or an in-ime drain the water from the jacket. This is *essential* in .her, but is always advisable in order to prevent water filter-he cylinder through minute leaks or through the packings. parts inside the cylinder become red-hot or nearly so, 'e ignitions are likely to occur. Any incombustible dust, n scale due to the oil, will readily heat and preignite. ılmost pure mineral oil should be used for lubricating the ; it forms little or no carbon scale. It is always well to ɔil gathering in the combustion-chamber of the cylinder; does this, the chamber should be cleaned often. To recog-nature explosions, run the engine on light load, then put ll load suddenly. If it runs smoothly at first and be-to lose power while giving seemingly violent impulses, continues to ignite when the ignition device is put out , there is premature ignition.

engines the cooling may be overdone, especially at light , certain temperature is required to properly vaporize the e imperfect combustion which generally exists in oil ɜ *increased thereby and* soot and carbon scale will result *sitate frequent cleansings.*

Advantages and Disadvantages.—As already stated, the ga and gasoline engine, considered as a machine for transformin the latent energy of fuel into useful mechanical work, is far superior in point of economy to the steam engine. This is espe ially the case where producer gas is used—that is, a gas made i the so-called Dowson apparatus, which can be made very cheaply and, while unfit for illuminating purposes, is an excellent fuel fo use in connection with the gas engine. In small units—that i up to about 100 horse power—it may be said in general th power may be had more cheaply from gas or gasoline engin than from steam engines. Furthermore, there being no boiler t fire, the attendance required is less. Where city gas is used it i only necessary to turn on the gas-cock and start the engine, whil with a producer the coal may be fed automatically into a hoppe On the other hand, where a heating-system is to be operated i connection with the power plant, the advantages possessed by th gas or gasoline engine, in point of economy, disappear, as the hea contained in the exhaust from a steam engine may be readily utilized for heating purposes. If the exhaust by itself is not sufficient for the purpose, it may be augmented by some liv steam from the boilers, and so the cost of heating may be reduced to a very small amount. Aside from this, the cost of operating gas engines is often greater than would appear at first sight. It is true that the fireman's services are dispensed with; but, on the other hand, the gas engine is a far more complicated machine than the steam engine, and consequently more difficult to handle. It is much more liable to get out of order, and while any intelligent machinist is capable of repairing such minor accidents as frequently occur in steam engines, it takes a man of experience in the building of gas engines to locate and remedy the troubles which are liable to occur in them. If, therefore, such a man is to be constantly employed to operate a small engine, the saving in attendance is very much reduced; while if a gas-engine expert is to be sent for every time the engine refuses to start, and the entire t kept idle until the trouble is removed, the saving referred ill soon disappear entirely.

he method of starting up gas and gasoline engines has always a weak point. After the gas has been turned on, or the line injected into the cylinder, it becomes necessary to turn engine over several times rapidly before the normal action ns. This may be done, readily enough, by hand in the smaller s, while in the larger ones some auxiliary device, such as a pressed-air tank or a small starting engine, is provided for ing the engine over. In medium-sized engines, however, the nse of such a device would be out of proportion to the cost ie engine, and in such cases the turning over of the engine mes an exceedingly laborious and often exasperating opera- This has always been a serious drawback to the use of gas nes, and one which, up to the present time, has not been ely removed.

ith regard to regulation, it has already been pointed out that gas engine, owing to the fact that it receives only one-fourth any impulses, is far inferior to the ordinary steam engine. desideratum is partially overcome by the use of extra heavy heels; but even then the regulation of the speed is not suffi- to meet the demands of certain kinds of power service. For ric lighting, for example, the variations in the speed of the engine are nearly always perceptible in the lamps, except e a storage battery is used in connection with the generator. combination of gas engine, dynamo, and storage battery, in offers special advantages as a lighting plant for large resi- es. The electric pressure is kept uniform by the storage ry; it may be started up at any instant, without preparation, sing the generator as a motor with the aid of current from battery, thus obviating the tedious operation of turning over ngine by hand; and, furthermore, the cost of fuel and attend- is comparatively small, so that for large residences and simi- uildings this kind of plant is both convenient and inexpen- operate. The same kind of a plant under special conditions is advantageous also in larger buildings. For example, in th large office building of the United Gas Improvement Co., i Philadelphia, which at the present writing is nearly completed the lighting is done both by gas and by the electric current. Th company being engaged in the manufacture of gas, this is natur ally the cheapest kind of fuel, and consequently the electric plan is driven by gas engines, and a storage battery is used in conne tion with the generators to accomplish the results above recite

In general, it may be said, that gas and gasoline engines can b used to advantage (*a*) where power is required at irregular inte vals, because they are always ready to start without preparation (*b*) where the amount of power is very small, because of the com parative economy both in first cost and cost of operation; (*c*) i locations where coal is expensive or fuel must be carried a co siderable distance, because gasoline may be more cheaply tran ported than coal, and consequently the gasoline engine would b cheaper to operate. The agricultural gasoline engine, for use o farms and plantations located far from a railroad, is a good e ample of this. There might be many other special conditions t make the gas or gasoline engine preferable, and no exact rul can be given in this matter. The data which have been given i the present chapter, together with a careful study of all existi conditions, will guide the intelligent engineer in choosing the kin of engine best adapted to each individual case.

PART VIII.

MATERIALS AND THEIR PROPERTIES.

CHAPTER XXV.

COMPOSITION AND GENERAL PROPERTIES.

e are accustomed to think of air and water as elements, but
iists easily prove that air is a mixture of various gases and
water is a combination of two gases. They have been unable,
ver, to decompose these two gases and have therefore con-
d that they are fundamental or elementary forms of matter.
nalyzing and decomposing a large number of materials they
discovered a large number of substances which they are unable
compose further. These substances, some of which are solids,
s liquids, and still others gases, under ordinary conditions,
call elements. Each element has definite and peculiar prop-
s. By their combination with each other they produce all
lifferent substances with which we are familiar. They always
ine with each other in certain definite proportions, which
ortions are multiples of the atomic weights given in the table
site.

oms and Molecules.—If we take a piece of iron and divide
to small fragments, we still find that these fragments retain
he properties which were characteristic of the original piece.
e divide these pieces still further up to the limit of observa-
by the microscope, they still retain these properties. It is
eived, however, that a point might be reached such that if
ion were carried still further the particles produced by this
division would lose some or all of the properties of the origi-
aterial. It is further believed that beyond this there can be

no further division. These last final particles are spol the **atoms** of an element. The smallest particle which (and still retain the distinctive peculiar properties of a s is called the **molecule.**

TABLE OF ELEMENTS.

Elements.	Symbol.	Atomic Weight.	Elements.	Symbol.
Aluminium, ...	Al	27.08	Molybdenum, ...	Mo
Antimony (Stibium), .	Sb	120.3	Nitrogen, ...	N
Arsenic, ...	As	75	Nickel, ...	Ni
Barium, ...	Ba	137	Niobium, ...	Nb
Beryllium, ...	Be	9.1	Osmium, ...	Os
Bismuth, ...	Bi	208	Oxygen, ...	O
Boron, ...	B	11.01	Palladium, ...	Pd
Bromine, ...	Br	79.963	Phosphorus, ...	P
Cadmium, ...	Cd	112.1	Platinum, ...	Pt
Cæsium, ...	Cs	132.9	Potassium (Kalium), .	K
Calcium, ...	Ca	40	Rhodium, ...	Rh
Carbon, ...	C	12	Rubidium, ...	Rb
Cerium, ...	Ce	140.2	Ruthenium, ...	Ru
Chlorine, ...	Cl	35.453	Samarium, ...	Sa
Chromium, ...	Cr	52.2	Scandium, ...	Sc
Cobalt, ...	Co	59	Sulphur, ...	S
Copper, ...	Cu	63.3	Selenium, ...	Se
Didymium, ...	Di	142.3	Silver (Argentum), . .	Ag
Erbium, ...	Er	166	Silicon, ...	Si
Fluorine, ...	Fl	19	Sodium (Natrium). . .	Na
Gallium, ...	Ga	69.9	Strontium, ...	Sr
Germanium, ...	Ge	72.3	Tantalum, .	Ta
Gold (Aurum), . . .	Au	197.2	Tellurium, ...	Te
Hydrogen, . . .	H	1.003	Thallium, ...	Tl
Indium, ...	In	113.7	Thorium, ...	Th
Iodine, ...	I	126.86	Tin (Stannum), . .	Sn
Iridium, . . .	Ir	193.2	Titanium, ...	Ti
Iron (Ferrum), ...	Fe	56	Tungsten (Wolfram), .	W
Lanthanum, . . .	La	138.5	Uranium, ...	Ur
Lithium, ...	Li	7.03	Vanadium, ...	Vd
Lead (Plumbum), . .	Pb	206.91	Ytterbium, ...	Yb
Magnesium, ...	Mg	24.38	Yttrium, ...	Y
Manganese, ...	Mn	55	Zinc, ...	Zn
Mercury, ...	Hg	200.4	Zirconium, . .	Zr

lmium and thulium (the element X of Soret) might also be m
h the latest researches seem to indicate that they and also erbium, (
are not simple substances, but rather mixtures of several

The weights given are not the actual weights of the atoms, as e atoms are inconceivably minute, but the relative weights. us the oxygen atom weighs about sixteen times as much as the drogen atom. As the latter is the lightest of all, it is taken as e standard of atomic weight.

Every substance is now supposed to be composed of an imense number of molecules, which, even in the solid state, are ver entirely at rest, and in the gaseous form are in a state of rpetual violent commotion, rushing about in straight lines in all rections with inconceivable rapidity.

The difficulty of proving or disproving the molecular theory s in our inability to determine the size or shape of a molecule any means in our power. The most powerful microscope fails terly to show them, and should some material for lenses be disvered infinitely superior to glass or other material at present in e, we should fall far short of appreciating a molecule through e vision.

The principal properties of different metals are their *malleaility*, or capability to stand hammering; their *ductility*, or power being drawn into wire-form; their *tenacity*, or strength; their *rdness;* their *fusibility*, or ease of melting under the application heat; and their *specific gravity*. (For melting-points see Chapr IV.)

The following table gives an idea of the order in which some the common metals stand:

Malleability.	Ductility.	Tenacity.	Fusibility.
Gold,	Platinum,	Iron,	Tin,
Silver,	Silver,	Copper,	Lead,
Aluminum,	Iron,	Aluminum,	Zinc,
Copper,	Copper,	Platinum,	Aluminum,
Tin,	Gold,	Silver,	Silver,
Lead,	Aluminum,	Zinc,	Gold,
Zinc,	Zinc,	Gold,	Copper,
Platinum,	*Tin,*	Tin,	Iron,
Iron.	*Lead.*	Lead.	Platinum.

Gravity, Specific.—The specific gravity of a body is the ratio of its weight to the weight of an equal volume of some other body assumed as a conventional standard. The standard usually adopted for solids and liquids is rain or distilled water at a common temperature. In bodies of equal magnitudes the specific gravities are directly as their weights or as their densities. In bodies of the same specific gravity their weights will be as the magnitudes. In bodies of equal weights the specific gravities are inversely as the magnitudes. The weights of different bodies are to each other in the compound ratio of their magnitudes and specific gravities. Hence, it is obvious that, speaking of the magnitude, weight, and specific gravity of a body, if any two of them are given, the third may be found. A body, immersed in a fluid will sink if its specific gravity be greater than that of the fluid; if it be less, the body will rise to the top and be only partly immersed; and if the specific gravity of the body and fluid be equal, it will remain at rest in any part of the fluid in which it may be placed. When a body is heavier than a fluid it loses as much of its weight when immersed as is equal to a quantity of the fluid of the same bulk or magnitude. If the specific gravity of the fluid be greater than that of the body, then the quantity of fluid displaced by the part immersed is equal to the weight of the whole body. The specific gravities of equal solids are as their parts immersed in the same fluid.

To Find the Specific Gravity of a Substance.—If it is heavier than water, weigh it in air and then weigh it suspended in water. The difference in weight is the weight of an equal bulk of water. Divide the weight in air by the weight of the equal bulk of water and the quotient is the specific gravity.

If the body floats put just the weight on it that is necessary to make it sink even with the surface of the water. Then from the sum of this weight and the weight in air subtract the weight in water. The difference is the weight of an equal bulk of water. Divide the weight in air by this and the quotient will be the specific gravity.

SPECIFIC GRAVITIES OF METALS.

		Specific gravity.	Weight per cu. in.
ıum		2.56 to 2.71	.0963
ɔny		6.66 to 6.86	.2439
h		9.74 to 9.90	.3544
Copper + Zinc 80 20 70 30 60 40 50 50		7.8 to 8.6	.3103 .3031 .3017 .2959
Copper, 95 to 80 Tin, 5 to 20		8.52 to 8.96	.3195
ım		8.6 to 8.7	.3121
n		1.58	
ium		5.0	
		8.5 to 8.6	
ıure		19.245 to 19.361	.6949
		8.69 to 8.92	.3195
ı		22.38 to 23.	.8076
ast.		6.85 to 7.48	.2604
Vrought		7.4 to 7.9	.2779
		11.07 to 11.44	.4106
nese		7. to 8.	.2887
sium		1.69 to 1.75	.0641
y	32°	13.60 to 13.62	.4915
	60°	13.58	.4900
	212°	13.37 to 13.38	.4828
		8.279 to 8.93	.3175
ım		20.33 to 22.07	.7758
um		0.865	
		10.474 to 10.511	.3791
ı.		0.97	
		7.69* to 7.932†	.2834
		7.291 to 7.409	.2652
ım		5.3	
en		17. to 17.6	
		6.86 to 7.20	.2526

the first column of figures the lowest are usually those of cast metals.

cific Gravity of Liquids.—The most obvious method of ring the specific gravity of any liquid is to take a vessel with it and weigh it. Then weigh the same vessel filled ater. Divide the weight of the substance by the weight of ter and the quotient will be the specific gravity.

hydrometer *used for* testing the specific gravity of liquids *of a graduated* tube of small diameter attached to a bulb containing air enough to make it float. Just below this air chamber is a small bulb containing enough mercury to keep the apparatus upright. The graduations on the tube give the specific gravity of the liquid in which the hydrometer is placed.

SPECIFIC GRAVITIES OF LIQUIDS AT 60° F.

Acid, Muriatic	1.200	Oil, Olive	.92
" Nitric	1.217	" Palm	.97
" Sulphuric	1.849	" Petroleum	.78 to .88
Alcohol, pure	.794	" Rape	.92
" 95 per cent	.816	" Turpentine	.87
" 50 "	.934	" Whale	.92
Ammonia, 27.9 per cent	.891	Tar	1.
Bromine	2.97	Vinegar	1.08
Carbon disulphide	1.26	Water	1.
Ether, Sulphuric	.72	" sea	1.026 to 1.03
Oil, Linseed	.94		

SPECIFIC GRAVITIES OF GASES AT 32° F.

Compared with air, pressure 1 atmosphere, 1 cu. ft. air weighs at this temperature and pressure .08071 pound.

Air	1.000	Hydrogen	.070
Ammonia (gas)	.597	Hydrogen sulphide	1.191
Carbonic acid gas	1.529	Marsh gas	.559
Carbon monoxide	.967	Nitrogen	.972
Chlorine	2.422	Nitrous oxide	1.527
Coal gas from	.340	Oxygen	1.105
" to	.450	Sulphurous acid gas	2.247
Hydrochloric acid gas	1.250	Steam (at 212°)	.469

Use of Tables.—*Example.*—A certain vessel contains when full 10 pounds of water. How many pounds of linseed oil will it contain? By looking in the table we find the specific gravity of linseed oil is $\frac{94}{100}$. Therefore the vessel will contain 10 × .94, or 9.4 pounds of linseed oil.

Example.—1 gallon of alcohol weighs at 60° F. 8.3 pounds. What will 1 gallon of linseed oil weigh? Divide 8.3 by the specific gravity of alcohol and multiply by the specific gravity of linseed oil. $8.3 \div .794 \times .94 = 9.88$ pounds.

WEIGHT OF A CUBIC FOOT OF SUBSTANCES.

NAMES OF SUBSTANCES.	Average Weight. lbs.
Aluminum,	162
Anthracite, solid, of Pennsylvania,	93
“ broken, loose,	54
“ “ moderately shaken,	58
“ heaped bushel, loose,	(80)
Ash, American white, dry,	38
Asphaltum,	87
Brass, (Copper and Zinc,) cast,	504
“ rolled,	524
Brick, best pressed,	150
“ common hard,	125
“ soft, inferior,	100
Brickwork, pressed brick,	140
“ ordinary,	112
Cement, hydraulic, ground, loose, American, Rosendale,	56
“ “ “ “ “ Louisville,	50
“ “ “ “ English, Portland,	90
Cherry, dry,	42
Chestnut, dry,	41
Clay, potters', dry,	119
“ in lump, loose,	63
Coal, bituminous, solid,	84
“ “ broken, loose,	49
“ “ heaped bushel, loose,	(74)
Coke, loose, of good coal,	62
“ “ heaped bushel,	(40)
Copper, cast,	542
“ rolled,	548
Earth, common loam, dry, loose,	76
“ “ “ “ moderately rammed,	95
“ as a soft flowing mud,	108
Ebony, dry,	76
Elm, dry,	35
Flint,	162

WEIGHT OF SUBSTANCES *continued*).

NAMES OF SUBSTANCES.	Average Weight. lbs
Glass, common window,	157
Gneiss, common,	168
Gold, cast, pure, or 24 carat,	1204
" pure, hammered,	1217
Granite,	170
Gravel, about the same as sand, which see.	
Gypsum (plaster of paris),	142
Hemlock, dry,	25
Hickory, dry,	53
Hornblende, black,	203
Ice,	58.7
Iron, cast,	450
" wrought, purest,	485
" " average,	480
Ivory,	114
Lead,	711
Lignum Vitæ, dry,	83
Lime, quick, ground, loose, or in small lumps,	53
" " " " thoroughly shaken,	75
" " " " per struck bushel,	(66)
Limestones and Marbles,	168
" " loose, in irregular fragments,	96
Magnesium,	109
Mahogany, Spanish, dry,	53
" Honduras, dry,	35
Maple, dry,	49
Marbles, see Limestones.	
Masonry, of granite or limestone, well dressed,	165
" " mortar rubble,	154
" " dry " (well scabbled,)	138
" " sandstone, well dressed,	144
Mercury, at 32° Fahrenheit,	849
Mica,	183
Mortar, hardened,	103
Mud, dry, close,	80 to 110

WEIGHT OF SUBSTANCES (*continued*).

NAMES OF SUBSTANCES.	Average Weight. Lbs.
Mud, wet, fluid, maximum,	**120**
Oak, live, dry,	**59**
“ white, dry,	**50**
“ other kinds,	**32** to **45**
Petroleum,	**55**
Pine, white, dry,	**25**
“ yellow, Northern,	**34**
“ “ Southern,	**45**
Platinum,	**1342**
Quartz, common, pure,	**165**
Rosin,	**69**
Salt, coarse, Syracuse, N. Y.,	**45**
“ Liverpool, fine, for table use,	**49**
Sand, of pure quartz, dry, loose,	**90** to **106**
“ well shaken,	**99** to **117**
“ perfectly wet,	**120** to **140**
Sandstones, fit for building,	**151**
Shales, red or black,	**162**
Silver,	**655**
Slate,	**175**
Snow, freshly fallen,	**5** to **12**
“ moistened and compacted by rain,	**15** to **50**
Spruce, dry,	**25**
Steel,	**490**
Sulphur,	**125**
Sycamore, dry,	**37**
Tar,	**62**
Tin, cast,	**459**
Turf or Peat, dry, unpressed,	**20** to **30**
Walnut, black, dry,	**38**
Water, pure rain or distilled, at 60° Fahrenheit,	**62⅓**
“ sea,	**64**
Wax, bees,	**60.5**
Zinc or Spelter,	**43.7**

Green *timbers usually weigh from* one-fifth to one-half more than dry.

WEIGHT OF VARIOUS MATERIALS.

1	bushel, heaped, bituminous coal	weighs	80	lbs.,	approximat
1	" " coke	"	37	"	"
1	" " lime	"	75	"	"
1	" (2748 cu. in.) charcoal	"	20	"	"
1	" struck, Rosendale cement	"	68	"	"
1	" " salt, coarse	"	56	"	"
1	" " wheat	"	60	"	"
1	" " corn	"	56	"	"
1	" " oats	"	30	"	"
1	barrel petroleum, 42 gallons,	"	275	"	"

Brick.—The sizes of bricks of different makers vary con erably, as do also bricks from the same maker, owing to the ferent heats to which they are subjected. The following are s common dimensions, as given in the handbook of the New Je Steel and Iron Company:

Description.	Inches.	Description.	Inches.
Baltimore front	$8\frac{1}{4}\times4\frac{1}{8}\times2\frac{3}{8}$	Maine	$7\frac{1}{2}\times3\frac{3}{4}\times$
Philadelphia front		Milwaukee	$8\frac{1}{2}\times4\frac{1}{8}$
Wilmington front		North River	$8\times3\frac{1}{2}$
Trenton front		Trenton	8×4
Croton	$8\frac{1}{2}\times4\times2\frac{1}{4}$	Ordinary	$7\frac{3}{4}\times3\frac{5}{8}$ $8\times4\frac{1}{2}$
Colabaugh	$8\frac{1}{4}\times3\frac{5}{8}\times2\frac{3}{8}$		

FIRE BRICK—{ Valentine's (Woodbridge, N. J.) . . . . $8\frac{7}{8}\times4\frac{3}{8}\times2\frac{1}{2}$ i

Downing's (Allentown, Pa.) . . . . $9\times4\frac{1}{2}\times2\frac{1}{2}$ i

To compute the number of bricks in a square foot of wall.—To the face dimensions o bricks used add the thickness of one joint of mortar, and multiply these togeth obtain the area. Divide 144 square inches by this area, and multiply by the r ber of times which the dimension of the brick, at right angles to its face, is tained in the thickness of the wall.

Example.—How many Trenton bricks in a square foot of 12-inch wall, the j being ¼ inch thick?

$$8+\tfrac{1}{4}\times2\tfrac{1}{4}+\tfrac{1}{4}=20.62;\ 144\div20.62=7;\ 7\times3=21 \text{ bricks per sq. ft.}$$

BRICK-WORK AND MASONRY.

Stone work is estimated by the perch of 25 cubic feet. Brick-wor estimated by the thousand, and for various thicknesses of wall runs:

9 in. wall or 1 brick in thickness, 14 bricks per superficial foot.
13 " " 1½ " " 21 " " "
18 " " 2 " " 28 " " "
22 " " 2½ " " 35 " " "

CHAPTER XXVI.

METALS IN COMMON USE.

Iron is the most important of all the metals known to man, as ll as the most useful. It has been one of the principal agents the civilization of the human race, and is at the present day ore extensively employed in the mechanical arts than any other tal. It is found in different conditions, but always in the state oxides, or as iron ore, that is, a sort of rusty metallic state. The ost common kind — the hematite or blood-stone — may be deribed as iron-rust solidified, or rendered concrete by water. After ng taken from the ground in the condition of ore, it is placed a blast-furnace and smelted, after which it is rendered fibrous d ductile by puddling. Spiegel iron or specular cast-iron is, as name implies, largely crystalline, presenting bright, mirror-like, avage planes.

Wrought-iron varies in specific gravity from 7·8 to 7·6; taking e mean at 7·7, a cubic foot will weigh 479·8721664 lbs., or nearly 80 lbs. Cast-iron varies in specific gravity from 7·5 to 6·9, the erage being 7·2.

	Wrought-Iron, Lbs.	Cast-Iron, Lbs.
A cubic foot	479·872	439·800
A cylindrical foot	376·891	344·407
A spherical foot	251·261	230·279
A cubic inch	0·2777	0·2544
A cylindrical inch	0·2181	0·1999
A spherical inch	0·1454	0·1333

Cast-iron is composed of about 91 per cent. of iron, 5 of caron, 2 of silicon, and 2 parts of sulphur, phosphorus, and other mpurities. It also contains manganese, nickel, cobalt, chromium, anadium, titanium, and tungsten in minute quantities. The arts of *steam-engines* generally made of wrought-iron are the *nk, eccentric-rods and straps,* valve- and piston-rods, connecting *ls, air-pump levers,* cross-heads for pumps, arms, etc.

Rust.—The red powder that falls from iron which ha been subjected to the action of moisture is the oxide of the and is termed rust.

Steel is one of the chemical modifications of iron, a con tion of iron and carbon. It is composed of different perce of each according to the purpose for which it is used. Th containing the least carbon is the softest, and that containi most is the hardest.

Cast-iron, wrought-iron, and steel can be distinguished each other by the difference in the grain — wrought-iron bein in the grain than cast, and steel finer than wrought; cast-ir ing short and brittle, wrought-iron fibrous, and steel void of

Steel and cast-iron are fusible; wrought-iron is malleabl tile, tough, fibrous, and possesses the quality of welding; also, is capable of being welded. From this it will be see steel possesses properties in common with both wrought- an iron. Malleable iron is composed of 99·5 per cent. of iron, of carbon, 0·076 of silicon, and the rest is sulphur and phorus. Its principal value consists in its property of re the chemical action of salt water or steam.

TABLE

SHOWING THE PERCENTAGE OF CARBON IN THE VARIOUS GRAD IRON AND STEEL.

Iron semi-steelified contains . . .	1–150	Carbo
Soft steel capable of welding . . .	1–120	"
Cast steel for common purposes . .	1–100	"
Cast steel requiring more hardness . .	1–90	"
Steel capable of standing a few blows, but quite unfit for drawing . . .	1–50	"
First approach to a steely, granulated cture	1–40	"
cast-iron	1–25	"
cast-iron	1–20	"
d cast-iron	1–15	"
rude iron . . .	1–12	"

TABLE

SHOWING THE ACTUAL EXTENSION OF WROUGHT-IRON AT VARIOUS TEMPERATURES.

Deg. Fah.	Length.	
32°	1·	
212	1·0011356	
392	1·0025757	Surface becomes straw-colored, deep-yellow, crimson, violet, purple, deep-blue, bright-purple.
572	1·0043253	
752	1·0063894	
932	1·0087730	Surface becomes dull, and then bright-red.
112	1·0114811	
652	1·0216024	Bright-red, yellow, welding heat, white heat.
192	1·0348242	
732	1·0512815	
912	Cohesion destroyed. Fusion perfect.	

Linear Expansion of Wrought-Iron.—The linear expansion ich a bar of wrought-iron undergoes, according to Daniell's rometer, when heated from the freezing- to the boiling-point, or m 32° to 212° Fah., is about $\frac{1}{880}$ of its length; at higher temratures the elongation becomes more rapid. Thus, it will be n how sensible a change takes place when iron undergoes a riation of temperature. A bar of iron 10 feet long, subject to ordinary change of temperature of from 32° to 180° Fah., will ngate more than $\frac{1}{8}$ of an inch, or sufficient to cause fracture in ne-work, strip the thread of a screw, or endanger a bridge, or, roof, or truss, or even push out a wall if brought in contact th it.

The expansion of volume and surface of wrought-iron is callated by taking the linear expansion as unity; then, following e geometrical law, the superficial expansion is twice the linear, d the cubical expansion is three times the linear.

Cast-iron expands $\frac{1}{162000}$ of its length for one degree of heat; e greatest change in the shade, in this climate, is $\frac{1}{1170}$ of its gth; *exposed to the sun's* rays, $\frac{1}{1000}$.

***'ast-iron** shrinks,* in cooling, from $\frac{1}{85}$ to $\frac{1}{98}$ of its length.

TABLE

DEDUCED FROM EXPERIMENTS ON IRON PLATES FOR STEAM-BOIL BY THE FRANKLIN INSTITUTE, PHILADA.

Iron boiler-plate was found to increase in tenacity, as its te perature was raised, until it reached a temperature of 550° abo the freezing-point, at which point its tenacity began to diminis

At 32° to 80° tenacity is 56,000 lbs., or $\frac{1}{7}$ below its maximum
" 570° " " 66,000 " the maximum.
" 720° " " 55,000 " the same nearly as at 30°
" 1050° " " 32,000 " nearly $\frac{1}{2}$ the maximum.
" 1240° " " 22,000 " nearly $\frac{1}{3}$ the maximum.
" 1317° " " 9,000 " nearly $\frac{1}{7}$ the maximum.

It will be seen by the above table that if a boiler should beco overheated by the accumulation of scale on some of its parts, an insufficiency of water, the iron would soon become reduced less than one-half its strength.

TABLE

SHOWING THE STANDARD WEIGHTS OF CAST-IRON WATER-PIPE.

3 inch, 15 lbs. per foot = 180 lbs. per length of 12 feet.
4 inch, 22 " " = 264 " " " "
6 inch, 33 " " = 400 " " " "
8 inch, 42 " " = 500 " " " "
10 inch, 60 " " = 720 " " " "
12 inch, 75 " " = 900 " " " "

TABLE

SHOWING THE STANDARD WEIGHTS OF CAST-IRON GAS-PIPE.

3 inch, 12½ lbs. per foot = 150 lbs. per length of 12 feet.
4 inch, 17 " " = 204 " " " "
6 inch, 30 " " = 360 " " " "
8 inch, 40 " " = 480 " " " "
10 inch, 50 " " = 600 " " " "
12 inch, 70 " " = 840 " " " "

TABLE

VING THE WEIGHT OF CAST-IRON PIPES, 1 FOOT IN LENGTH, FROM ¼ CH TO 1¼ INCHES THICK AND FROM 3 INCHES TO 24 INCHES DIAMETER.

in Inches.	Thickness in Inches.								
	¼ Lbs.	⅜ Lbs.	½ Lbs.	⅝ Lbs.	¾ Lbs.	⅞ Lbs.	1 Lbs.	1⅛ Lbs.	1¼ Lbs.
	8½	12½	17¼	22¼	27½	......	......	......	......
½	9¼	14¼	19½	25¼	31¼	......	......	......	......
	10	16¾	22	28½	35	......	......	......	......
½	11¾	18	24½	31½	38¾	......	......	......	......
	13	19¾	27	34½	42¼	50½	59	......	......
½	15	21½	29½	37½	46	54¾	63¾	......	......
	......	23½	32	40¾	49¾	59	68¾	78¾	88¾
½	......	25¼	34½	43¾	53½	63½	73½	84¼	95
	......	27¼	36¾	46¾	56¾	67¾	78½	89¾	101¼
½	......	29	39	50	60¾	72	83½	95¼	107½
	......	30¾	41¾	53	64½	76¼	88½	100¾	113½
½	......	33	44½	56¼	68¼	80¾	93½	106½	120
	......	34½	46½	59	71¾	84¾	98½	111¾	125¾
½	......	36¼	49	62	75½	89	103	117½	132
	......	38¼	51½	65¼	79¼	93½	108	122¾	138
½	......	......	54	68¼	82¾	97¾	112¾	128½	144¼
	......	......	56½	71¼	86½	102	117¾	134	150¼
½	......	......	59	76¼	90	106¼	122¾	139½	156½
	......	......	61¼	77½	93½	110½	127½	145	162½
	......	......	......	82¾	101¼	118¼	137½	154	173½
	......	......	......	89¼	108¼	126½	146¼	165¼	185¼
	......	......	......	95¼	115¾	135¼	156¼	176¼	198
	......	......	......	......	123¼	143	166	187½	211¼
	......	......	......	......	130¼	152½	178½	198¼	223½
	......	......	......	......	137	161¼	185¼	209	235¼
	......	......	......	......	......	169¼	195¾	222¼	247
	......	......	......	......	......	178	205¼	233¼	259
	......	......	......	......	......	......	214	243½	273¼
	......	......	......	......	......	......	223½	244¾	285¼
	......	......	......	......	......	......	233½	265½	298¼
	......	......	......	......	......	......	245¼	277½	310½

TABLE

SHOWING THE WEIGHT OF CAST-IRON BALLS FROM 3 TO 13 INCHES IN DIAMETER.

Diam. in Inches..	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾
Wt. in Pounds...	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼	52½	58	64

Diam. in Inches...	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½	12	13
Wt. in Pounds.....	70½	77¼	84¼	92½	100¼	109	118	127½	137¾	148¼	159½	171	183¼	209½	238	302

To find the weight of any cast-iron ball, cube the diameter, and multiply by the decimal ·5236; the product will be the number of cubic inches in the ball, which, if multiplied by the decimal ·2607, will give the weight of the ball in pounds.

WEIGHT OF CAST-IRON PLATES PER SUPERFICIAL FOOT AS PER THICKNESS.

Thickness in Inches..........	⅛	¼	⅜	½	⅝	¾	⅞	1

For Calculating the Weight of Shafting, etc.

Diameter in Inches........	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛
Weight in Pounds.........	¾	1	1½	2	2¾	3½	4¼	5	6	7	8	9½	10¼	12

Diameter in Inches.......	2¼	2⅜	2½	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞
Weight in Pounds..........	13½	15	16¾	18¼	20	22	24	26	28	30¼	32½	35	37¼	40

Diameter in Inches........	4	4⅛	4¼	4⅜	4½	4⅝	4¾	4⅞	5	5¼	5½	5¾	6
Weight in Pounds.........	42½	45¼	48	50¾	53¾	56¾	60	63	66¾	73¼	80¼	87¾	95½

TABLE

SHOWING THE WEIGHT OF CAST-IRON BALLS FROM 3 TO 13 INCHES IN DIAMETER.

Inches...	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾
Wt. in Pounds...	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼	52½	58	64

Diam. in Inches...	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½	12	13
Wt. in Pounds.....	70½	77¼	84¼	92½	100¼	109	118	127½	137¾	148¼	159½	171	183¼	209½	238	302

To find the weight of any cast-iron ball, cube the diameter, and multiply by the decimal ·5236; the product will be the number of cubic inches in the ball, which, if multiplied by the decimal ·2607, will give the weight of the ball in pounds.

WEIGHT OF CAST-IRON PLATES PER SUPERFICIAL FOOT AS PER THICKNESS.

Thickness in Inches..........	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1

company.

DIAMETER.			Thick-ness.	CIRCUMFERENCE.		TRANSVERSE AREAS.			Length of Pipe per sq. ft. of		Length of Pipe containing one cubic foot.	Nominal Weight per foot.	Number of Threads per inch of Screw.
Nominal Internal.	Actual External.	Actual Internal.		External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.			
inches.	inches.	inches.	inches.	inches.	inches.	sq. ins.	sq. ins.	sq. ins.	feet.	feet.	feet.	pounds.	
⅛	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
¼	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.78	751.2	.559	18
½	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
¾	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8

WEIGHT OF SHEETS OF WROUGHT IRON, STEEL, COPPER, AND BRASS.

Weights per Sq. Foot. Thickness by American (Browne & Sharpe's) Gauge.

No. of Gauge.	Thickness in inches.	Iron.	Steel.	Copper.	Brass.
0000	.46	18.46	18.70	20.84	19.69
000	.4096	16.44	16.66	18.56	17.53
00	.3648	14.64	14.83	16.53	15.61
0	.3249	13.04	13.21	14.72	13.90
1	.2893	11.61	11.76	13.11	12.38
2	.2576	10.34	10.48	11.67	11.03
3	.2294	9.21	9.33	10.39	9.82
4	.2043	8.20	8.31	9.26	8.74
5	.1819	7.30	7.40	8.24	7.79
6	.1620	6.50	6.59	7.34	6.93
7	.1443	5.79	5.87	6.54	6.18
8	.1285	5.16	5.22	5.82	5.50
9	.1144	4.59	4.65	5.18	4.90
10	.1019	4.09	4.14	4.62	4.36
11	.0907	3.64	3.69	4.11	3.88
12	.0808	3.24	3.29	3.66	3.46
13	.0720	2.89	2.93	3.26	3.08
14	.0641	2.57	2.61	2.90	2.74
15	.0571	2.29	2.32	2.59	2.44
16	.0508	2.04	2.07	2.30	2.18
17	.0453	1.82	1.84	2.05	1.94
18	.0403	1.62	1.64	1.83	1.73
19	.0359	1.44	1.46	1.63	1.54
20	.0320	1.28	1.30	1.45	1.37
21	.0285	1.14	1.16	1.29	1.22
22	.0253	1.02	1.03	1.15	1.08
23	.0226	.906	.918	1.02	.966
24	.0201	.807	.817	.911	.860
25	.0179	.718	.728	.811	.766
26	.0159	.640	.648	.722	.682
27	.0142	.570	.577	.643	.608
28	.0126	.507	.514	.573	.541
29	.0113	.452	.458	.510	.482
30	.0100	.402	.408	.454	.429
31	.0089	.358	.363	.404	.382
32	.0080	.319	.323	.360	.340
33	.0071	.284	.288	.321	.303
34	.0063	.253	.256	.286	.270
35	.0056	.225	.228	.254	.240

As there are many gauges in use differing from each other, and even the thicknesses of a certain specified gauge, as the Birmingham, are not assumed the same by all manufacturers, orders for sheets and wire should always state the weight per square foot, or the thickness in thousandths of an inch.

opper is, after iron, one of the most useful metals. It is very
leable and ductile, so that it is largely used in sheets and
s, and its tensile strength, though less than that of iron, is
high, varying from 20,000 to 30,000 pounds per square inch.
a trifle heavier than iron, but its high electric conductivity
es it preferable to iron for electric work in spite of this and
reater cost. The effect of heating copper is to reduce its
igth, as will be seen in the following table:

TABLE

ING THE STRENGTH OF COPPER BOILER PLATES AT DIFFERENT
MPERATURES, DEDUCED FROM EXPERIMENTS BY THE FRANKLIN IN-
TUTE OF PHILA. THE STANDARD STRENGTH AT 32° BEING 32,800
. PER SQUARE INCH.

Temperature above 32°.	Diminution of Strength.		Temperature above 32°.	Diminution of Strength.
90°	0·0175	9	660°	0·3425
180	0·0540	10	769	0·4398
270	0·0926	11	812	0·4944
360	0·1513	12	880	0·5581
456	0·2046	13	989	0·6691
460	0·2133	14	1000	0·6741
513	0·2446	15	1200	0·8861
532	0·2558	16	1300	1·000

will be seen from the above table, that, in being heated from
freezing-point to the boiling-point of water, copper loses 5
ent. of its strength; at 550° it loses about one-quarter of its
gth; and at 1332° loses all its tenacity.

ire copper is mostly used in wires and sheets. The weights
ifferent wires will be found in the chapter on electricity,
the weights of sheets will be found in a table on page 615.
d with zinc, tin, and lead it forms a number of valuable
s which are used enormously in the mechanic arts. The
below gives the *approximate* composition and use of many
ese alloys.

Alloys and Compositions.

	Copper.	Zinc.	Tin.	Antimony.	Lead.	Nickel.
Brass for locomotive bearings.....	50·	2·5	5·	....	5	
Brass for glands....................	65·	0·5	8·			
Brass engine bearings..............	50·	1·8	6·5			
Yellow brass for turning...........	40·	20·				
Brass richer..........................	50·	10·				
Box metal.............................	80·	10·				
Red brass.............................	70·	10·	....	....	5	
Flanges to stand brazing..........	64·	2·	....	....	2	
Tough brass engine work..........	100·	15·	15·			
Tough brass for heavy bearings..	160·	5·	25·			
Muntz metal..........................	90·	60·				
White metal..........................	11·	11·	42·6	85·2		
White metal, hard..................	104·7	38·7	6·6			
Bronze red...........................	130·5	19·5				
Bronze yellow.......................	100·8	46·8	2·4			
Gun metal for bearings............	90·3	9·67	0·3			
Bell metal for large bells..........	80·	....	20·			
Britannia metal.....................	1·	2·	81·	16·		
Brass for sheets.....................	84·7	15·3				
Nickel-silver, English..............	60·	17·8	....	....	.....	22·
Nickel-silver, Parisian.............	66·	13·6	....	....	.....	19·
German silver.......................	50·	25·	....	....	.....	25·

Brass or gun-metal is used for main-bearings of marine-en and propeller-shafts, link-blocks, air-pump buckets, head- and valves, stern-tube bushes, propellers, and steam- and water-c White metal is frequently used as a lining for main prop shaft and tunnel-bearings. Its chief value consists in its friction and lubricating properties, while its disadvantages that, if it becomes overheated, it will melt and run out o bearing. Muntz metal is used for surface-condenser tubes, and circulating-pump rods, and surface-condenser tube-plates. n *malleable*, has a high tensile strength, is very durable, and le *to* corrosion.

Babbitt's Metal.—Its composition is as follows: Four pounds copper, eight pounds of regulus of antimony, and eighty-eight pounds of tin. The copper is first melted; the tin and the regulus of antimony are then added. After the metals have been used a short time, and brought to a dull red heat, it is fit for use.

Another durable alloy for the journal-boxes of steam-engines is copper, 84; zinc, 8; tin, 2; lead, 4; and iron, 5 parts.

Bronze Alloy.—Copper, 80; tin, 18; zinc, 2. If, after casting, and while still red hot, cold water is poured over it, it becomes harder, and finer in grain, and tougher, as the tin, instead of separating, as happens when the bronze cools slowly, remains mixed, and the alloy retains its compactness.

Solder.—The following solder will braze steel or iron, and may be found very useful in case of a valve-stem or other light portion of an engine or machine breaking at a time when it is important that the engine or machine should continue work: Silver, 19 parts; copper, 1 part; brass, 2 parts.

Silver solder is generally composed of 4 parts silver and 2 parts yellow brass. Pure copper, in thin strips, is generally used for soldering-irons. Plumbers' solder is composed of 2 parts tin and 4 parts lead. This solder melts at about 450° Fah. Tinsmiths' solder is composed of 4 parts tin and 2 parts lead. This solder melts at about 350° Fah. Bismuth solder is composed of 7 parts bismuth, 5 parts lead, and 3 parts tin. This solder melts at about 225° Fah. All tin and lead solders become more fusible the more tin they contain. Thus, 1 part tin and 10 parts lead melt at about 550° Fah.; while 6 parts tin and 1 part lead melt at about 375° Fah. All the tin, lead, and bismuth solders become more fusible the more lead and bismuth they contain.

Delta metal, which is a tough, strong metal capable of being forged, cast, and receiving a high polish, consists of approximately 5 per cent. copper, 30 per cent. zinc, and 5 per cent. iron. has a tensile strength about three-quarters that of wrought iron.

TABLE OF WEIGHTS PER LINEAL FOOT OF BRASS AND COPPER ROD.

	BRASS.		COPPER.	
INCHES.	ROUND.	SQUARE.	ROUND.	SQUARE.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*
1-16	.011	.014	.01155	.0147
⅛	.045	.055	.047	.060
3-16	.100	.125	.106	.13497
¼	.175	.225	.189	.241
5-16	.275	.350	.296	.377
⅜	.395	.510	.426	.542
7-16	.540	.690	.579	.737
½	.710	.905	.757	.964
9-16	.90	1.15	.958	1.22
⅝	1.10	1.40	1.182	1.51
11-16	1.35	1.72	1.431	1.82
¾	1.66	2.05	1.703	2.17
13-16	1.85	2.40	1.998	2.54
⅞	2.15	2.75	2.318	2.95
15-16	2.48	3.15	2.660	3.39
1	2.85	3.65	3.03	3.86
1 1-16	3.20	4.08	3.42	4.35
1 ⅛	3.57	4.55	3.831	4.88
1 3-16	3.97	5.08	4.269	5.44
1 ¼	4.41	5.65	4.723	6.01
1 5 16	4.86	6.22	5.21	6.63
1 ⅜	5.35	6.81	5.723	7.24
1 7-16	5.86	7.45	6.255	7.97
1 ½	6.37	8.13	6.811	8.67
1 9-16	6.92	8.83	7.39	9.41
1 ⅝	7.48	9.55	7.993	10.18
1 11-16	8.05	10.27	8.45	10.73
1 ¾	8.65	11.00	9.27	11.80
1 13-16	9.29	11.82	9.76	12.43
1 ⅞	9.95	12.68	10.642	13.55
1 15-16	10.58	13.50	11.11	14.15
2	11.25	14.35	12.108	15.42
2⅛	12.78	16.27	13.668	17.42
2¼	14.32	18.24	15.325	19.51
2⅜	15.96	20.32	17.075	21.74
2½	17.68	22.53	18.916	24.09
2⅝	19.50	24.83	20.856	26.56
2¾	21.40	27.25	22.891	29.05
2⅞	23.39	29.78	25.019	31.86
3	25.47	32.43	27.243	34.69
3¼	30.45	38 77	31.972	40.71
3½	35.31	44.96	37.081	47.22
4	46.124	58.73	48.433	61.67

To find the weight of Octagon Rod, take the weight of Round Rod of a given size and multiply by 1 084.

To find the weight of Hexagon Rod, take the weight of Round Rod of a given size and multiply by 1 12.

These tables are theoretically correct, but variations must be expected in practice.

TABLE OF WEIGHTS PER LINEAL FOOT OF SEAMLESS BRASS AND COPPER TUBING.

IRON PIPE SIZES.

Same as Iron Pipe.	Exact O. D.	Nominal Outside Diameter.	Approximate Weight per Lineal Foot.	
			Brass.	Copper.
Inches.	Inches.	Inches.	Lbs.	Lbs.
⅛	.405	3-8	.25	.26
¼	.540	9-16	.43	.45
⅜	.675	11-16	.62	.65
½	.840	13-16	.90	.95
¾	1.05	1 1-16	1.25	1.32
1	1.315	1 5-16	1.70	1.79
1¼	1.66	1 5-8	2.50	2.63
1½	1.90	1 7-8	3.	3.16
2	2.375	2 3-8	4.	4.21
2½	2.875	2 7-8	5.75	6.05
3	3.50	3 1-2	8.30	8.74
3½	4.00	4	10.90	11.47
4	4.5	4 1-2	12.70	13.37
4½	5.00	5	13.90	14.63
5	5.563	5 9-16	15.75	16.58
6	6.625	6 5-8	18.31	19.23

TABLE OF WEIGHTS PER LINEAL FOOT OF SEAMLESS DRAWN BRASS AND COPPER TUBING.

STANDARD SIZES.

CARRIED IN STOCK IN 12-FEET LENGTHS.

Outside Diameter.	B. & S. Gauge.	Stubs' Gauge.	Weight per Ft.		Outside Diameter.	B. & S. Gauge.	Stubs' Gauge.	Weight per Ft.	
			Brass.	Copper.				Brass.	Copper.
			Lbs.	Lbs.				Lbs.	Lbs.
1-8	20	21	.034	.036	1 5-8	12	14	1.49	1.56
3-16	20	21	.057	.060	1 3-4	11	13	1.82	1.91
1-4	18	20	.086	.092	2	11	13	2.09	2.20
5-16	18	20	.113	.119	2 1-4	10	12	2.70	2.83
3-8	17	19	.161	.169	2 1-2	10	12	3.01	3.16
7-16	17	19	.193	.203	2 3-4	10	12	3.33	3.51
1-2	16	18	.255	.268	3	9	11	4.00	4.20
9-16	16	18	.291	.305	3 1-4	8	10	4.84	5.06
5-8	16	18	.325	341	3 1-2	8	10	5.22	5.49
3-4	15	17	.46	.49	4	8	10	5.98	6.28
7-8	15	17	.55	.58	4 1-4	8	10	6.38	6.69
1	14	16	70	.73	4 1-2	8	10	6.77	7.11
1 1-8	14	16	.78	.82	4 3-4	8	10	7.15	7.51
1 1-4	13	15	.99	1.04	5	8	10	7.55	7.93
1 3-8	12	14	1.22	1.29	6	8	10	9.10	9.55
1 1-2	12	14	1.36	1.44	6 3-6	5	7	12.93	13.60

TABLE OF WEIGHTS PER SQUARE FOOT OF COPPER AND BRASS SHEETS.

AMERICAN, OR B. & S. GAUGE.		COPPER.	BRASS.
No.	Thickness.	Lbs.	Lbs.
0000	.46 in., or 7-16 in. full	20.838	19.688
000	.40964 in.	18.557	17.533
00	.3648 “ or ⅜ in. scant	16.525	15.613
0	.32486 “	14.716	13.904
1	.2893 “	13.105	12.382
2	.25763 “ or ¼ in. full	11.670	11.027
3	.22942 “	10.393	9.819
4	.20431 “	9.255	8.745
5	.18194 “ or 3-16 in. scant	8.242	7.788
6	.16202 “	7.340	6.935
7	.14428 “	6.536	6.175
8	.12849 “ or ⅛ in. full	5.821	5.499
9	.11443 “	5.183	4.898
10	.10189 “	4.616	4.361
11	.090742“	4.110	3.884
12	.0808 “	3.66	3.457
13	.0720 “	3.26	3.08
14	.06408 “	2.90	2.743
15	.057068“	2.585	2.442
16	.05082 “	2.302	2.173
17	.045257“	2.05	1.937
18	.0403 “	1.825	1.725
19	.0359 “	1.626	1.536
20	.0320 “	1.448	1.367
21	.02846 “	1.289	1.218
22	.02535 “	1.148	1.085
23	.02257 “	1.023	.966
24	.0211 “	.910	.860
25	.0179 “	.811	.766
26	.0159 “	.722	.682
27	.01419 “	.643	.608
28	.01264 “	.573	.541
29	.01126 “	.510	.482
30	.01003 “	.454	.429
31	.0089 “	.404	.382
32	.0079 “	.360	.340
33	.0071 “	.321	.303
34	.0063 “	.286	.269
35	.0056 “	.254	.240
36	.0050 “	.226	.214
37	.00445 “	.202	.191
38	.00396 “	.180	.170
39	.00353 “	.160	.151
40	.00314 “	.142	.135

These weights are theoretically correct, but variations must be expected in practice.

BLE SHOWING NUMBER OF BELT RIVETS AND BURS TO THE POUND.

No.	¼	5-16	⅜	7-16	½	9-16	⅝	¾	⅞	1	1⅛	1¼	1⅜	Burs.
3	......	......	......	......	......	......	......	......	......	....	....	....	....	70
4	......	......	......	......	......	......	......	......	......	....	....	....	....	78
5	....	......	......	......	64	60	53	48	46	44	39	36	32	85
6	......	......	105	100	96	90	74	68	61	56	54	50	46	180
7	211	189	171	160	150	140	132	110	97	91	79	72	63	368
8	266	248	227	200	172	157	147	136	116	100	98	88	71	417
9	365	330	261	248	228	220	184	169	156	133	124	118	99	600
10	411	376	336	305	257	249	223	206	180	162	...	....	....	820
11	416	400	360	338	320	......	......	......	......	....	....	....	....	944
12	545	475	400	342	325	308	292	257	221	190	....	....	....	1167
13	799	640	547	502	448	400	392	316	......	....	....	....	....	1442
14	104	995	816	784	616	550	528	......	......	....	....	....	....	1620
15	......	......	......	......	......	......	......	......	......	....	....	....	....	3513

Lead, which is widely employed in the arts, differs radically its properties from iron and copper. It melts at a fairly low nperature (about 600° F.), is very soft and malleable, and is nost entirely inelastic. It is only slightly soluble in water, the mation of a coating of lead carbonate preventing the further gress of solution. It is not attacked by most acids and is refore used largely for vessels employed in their manufacture. a constituent of paints in the forms of white lead (lead carnate) and red lead (lead oxide) its use is enormous.

In electrical work it has two chief uses: 1. In storage battes the frames of the plates are formed of pure lead and the active terials of lead compounds. 2. For conductors to be used in derground or submarine work it is drawn over the insulation the conductor so as to enclose it in a water-proof lead pipe for purpose of keeping the insulation of the conductor dry.

Lead is used largely in sheets and pipes to convey or hold uids. Its small tensile strength renders it unfit for use where y great strain is to be put upon it; but, on the other hand, its edom from attack by oxygen and many oxidizing agents kes it exceedingly useful.

Sheet lead is regularly made with weights per square foot of pounds, 3 pounds, 3½ pounds, 4 pounds, 4½ pounds, 5 pounds, pounds, 7 pounds, and upward.

Lead pipe for *use as water* pipe is made in regular sizes and *ights as given in the table* following.

LEAD AND TIN-LINED LEAD PIPE.

Calibre of Pipe.	Weight per Rod and Foot	Average length of Coils.	Calibre of Pipe.	Weight per Foot.	Ave len of C
⅜ in.	7 lbs. per rod		1½ in.	3½ lbs. per foot	45
"	10 oz. per foot	100 feet	"	4½ lbs. "	40
"	1 lb. "	125 "	"	5 lbs. "	42
"	1¼ lbs. "	100 "	"	6½ lbs. "	32
"	1½ lbs. "	85 "	"	8 lbs. "	25
½ in.	9 lbs. per rod	150 "	1¾ in.	4 lbs. "	50
"	¾ lbs. p. foot	135 "	"	5 lbs. "	40
"	1 lb. "	125 "	"	6½ lbs. "	32
"	1¼ lbs. "	100 "	"	8½ lbs. "	24
"	1½ lbs. "	140 "	2 in.	4¾ lbs. "	30
"	1¾ lbs. "	120 "	"	6 lbs. "	35
"	2 lbs. "	100 "	"	7 lbs. "	30
"	2¼ lbs. "	90 "	"	8 lbs. "	25
"	2½ lbs. "	85 "	"	9 lbs. "	23
"	3 lbs. "	70 "	2½ in.	8 lbs. "	12
⅝ in.	14 lbs. per rod		"	11 lbs. "	12
"	1 lb. per foot	125 "	"	14 lbs. "	12
"	1½ lbs. "	85 "	"	17 lbs. "	12
"	2 lbs. "	100 "	3 in.	9 lbs. "	12
"	2¼ lbs. "	95 "	"	12 lbs. "	12
"	2½ lbs. "	85 "	"	16 lbs. "	12
"	2¾ lbs. "	75 "	"	20 lbs. "	12
"	3 lbs. "	70 "	3½ in.	12½ lbs. "	12
"	3½ lbs. "	60 "	"	15 lbs. "	12
¾ in.	16 lbs. p. rod.		"	18½ lbs. "	12
"	1¼ lbs. per foot	100 "	"	22 lbs. "	12
"	1½ lbs. "	80 "	4 in.	12 lbs. "	12
"	1¾ lbs. "	75 "	"	16 lbs. "	12
"	2 lbs. "	65 "	"	21 lbs. "	12
"	2½ lbs. "	85 "	"	25 lbs. "	12
"	3 lbs. "	70 "	4½ in.	14 lbs. "	12
"	3½ lbs. "	60 "	"	18 lbs. "	12
"	4½ lbs. "	45 "	5 in.	20 lbs. "	12
1 in.	24¾ lbs. p. rod.		"	31 lbs. "	10
"	2 lbs. per foot	65 "			
"	2½ lbs. "	50 "			
"	3¼ lbs. "	65 "			
"	4 lbs. "	50 "			
"	4¾ lbs. "	45 "			
1¼ in.	2 lbs. "	50 "			
"	2½ lbs. "	50 "			
"	3 lbs. "	45 "			
"	3¾ lbs. "	55 "			
"	4¾ lbs. "	45 "			
"	6 lbs. "	35 "			

WEIGHT OF LEAD PIPE FOR A GIVEN HEAD OF WATER

Head or Number of Feet Fall.	Pressure per sq. inch.	Calibre and Weight per Foot.						
		Letter.	⅜ inch.	½ inch.	⅝ inch.	¾ inch.	1 inch.	1¼
30 ft.	15 lbs.	D	10 oz.	¾ lb.	1 lb.	1¼ lbs.	2 lbs.	2
50 ft.	25 lbs.	C	12 oz.	1 lb.	1½ lbs.	1¾ lbs.	2½ lbs.	3
75 ft.	38 lbs.	B	1 lb.	1¼ lbs.	2 lbs.	2¼ lbs.	3¼ lbs.	3
[illegible] ft.	50 lbs.	A	1¼ lbs.	1¾ lbs.	2½ lbs.	3 lbs.	4 lbs.	4
[illegible]t.	75 lbs.	AA	1½ lbs.	2 lbs.	2¾ lbs.	2½ lbs.	4¾ lbs.	6
[illegible]	100 lbs.	AAA	1¾ lbs.	3 lbs.	3½ lbs.	4¾ lbs.	6 lbs.	

CHAPTER XXVII.

BOLTS, NUTS, SCREWS, ETC.

ws—Standard Thread.—There are three different threads the V thread, the Whitworth, and the Sellers or U. S. :d, the proportions of which are given below.

" pitch " of a thread is the distance which it travels length- r one revolution of the screw.

thickness or depth of a nut, to give equal strength, must .1 to the outside diameter of the screw or bolt.

TABLE

ГHE PROPORTIONS OF THE UNITED STATES OR SELLERS' STANDARD THREADS FOR SCREWS, NUTS, AND BOLTS.

Number of Threads per Inch.	Diameter of Screw at the Root of the Thread in Decimals of an Inch.	Width of Top and Bottom of Thread in Decimals of an Inch.	Outside Diameter of Screw in Inches.	Number of Threads per Inch.	Diameter of Screw at the Root of the Thread in Decimals of an Inch.	Width of Top and Bottom of Thread in Decimals of an Inch.
20	·185	·0062	2	4½	1·712	·0277
18	·240	·0074	2¼	4½	1·962	·0277
16	·294	·0078	2½	4	2·176	·0312
14	·344	·0089	2¾	4	2·426	·0312
13	·400	·0096	3	3½	2·629	·0357
12	·454	·0104	3¼	3½	2·879	·0357
11	·507	·0113	3½	3¼	3·100	·0384
10	·620	·0125	3¾	3	3·317	·0413
9	·731	·0138	4	3	3·567	·0413
8	·837	·0156	4¼	2⅞	3·798	·0435
7	·940	·0178	4½	2¾	4·028	·0454
7	1·065	·0178	4¾	2⅝	4·256	·0476
6	1·160	·0208	5	2½	4·480	·0500
6	1·284	·0208	5¼	2½	4·730	·0500
5½	1·389	·0227	5½	2⅜	4·953	·0526
5	1·491	·0250	5¾	2⅜	5·203	·0528
5	1·616	·0250	6	2¼	5·423	·0555

WEIGHT OF BOLTS PER 100.

SQUARE HEADS.

Diam.	¼	$\frac{5}{16}$	⅜	$\frac{7}{16}$	½	$\frac{9}{16}$	⅝	¾	⅞	1
Length.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1½ in.	3.9	6.2	9.7	14.7	20.4	26.	37.	58.	. . . . .	. .
2 "	4.6	7.2	11.3	16.5	22.4	29.	39.9	63.2	97.7	[illegible]
2½ "	5.4	8.2	12.9	18.5	25.	32.2	44.1	69.	105.6	[illegible]
3 "	6.2	9.3	14.5	20.5	27.8	35.4	48.3	75.2	113.8	[illegible]
3½ "	6.9	10.4	16.1	22.6	30.6	38.7	52.5	81.4	122.	[illegible]
4 "	7.6	11.5	17.7	24.7	33.4	42.	56.7	87.6	130.2	[illegible]
4½ "	8.3	12.6	19.2	26.8	36.2	45.3	60.9	93.8	138.4	[illegible]
5 "	9.	13.7	20.7	28.9	39.	48.6	65.1	100.	146.6	[illegible]
5½ "	9.7	14.8	22.2	31.	41.8	51.9	69.2	106.1	154.9	[illegible]
6 "	10.4	15.9	23.7	33.1	44.6	55.2	73.4	112.2	163.2	[illegible]
6½ "	11.1	17.	25.2	35.2	47.4	58.5	77.6	118.3	171.5	[illegible]
7 "	11.8	18.1	26.7	37.3	50.2	61.8	81.8	124.4	179.8	[illegible]
7½ "	12.5	19.2	28.2	39.4	53.1	65.1	86.	130.5	187.1	[illegible]
8 "	13.2	20.3	29.7	41.5	56.	68.5	90.	136.6	195.4	[illegible]

BREAKING STRAIN OF BOLTS.

⅜ in.	$\frac{7}{16}$ in.	½ in.	$\frac{9}{16}$ in.	⅝ in.	$\frac{11}{16}$ in.	¾ in.	⅞ in.	1 in.
4,575 lbs.	4,950 lbs.	7,700 lbs.	9,000 lbs.	11,225 lbs.	15,000 lbs.	18,200 lbs.	23,500 lbs.	30,00 lbs.
1⅛ in.	1¼ in.	1½ in.	1¾ in.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.
35,500 lbs.	41,000 lbs.	63,000 lbs.	88,000 lbs.	120,000 lbs.	145,000 lbs.	180,000 lbs.	220,000 lbs.	275,0 lbs.

U. S. TAPPED NUTS.

NUMBER IN 100 POUNDS.

Size of Bolt.	Threads to Inch.	Square Nuts, Cupped.	Hexagon Nuts, Cupped.
$\frac{3}{16}$ inch.	24	17,000	20,500
¼ "	20	7,500	9,000
$\frac{5}{16}$ "	18	4,500	5,500
⅜ "	16	2,720	3,200
$\frac{7}{16}$ "	14	1,900	2,170
½ "	13 (or 12)	1,250	1,500
$\frac{9}{16}$ "	12	980	1,150
⅝ "	11	700	850
$\frac{11}{16}$ "	11	425	545
¾ "	10	400	520
⅞ "	9	270	340
1 "	8	180	230

LENGTHS OF THREADS CUT ON BOLTS.

th of Bolts.	¼ & 5/16	⅜ & 7/16	½ & 9/16	⅝	¾	⅞	1	1⅛	1¼
o 1½ in.	¾	⅞	1	1¼	. . .	. . .	. . .	. . .	. . .
2 "	⅞	1	1	1¼	1½	1¾	. . .	. . .	. . .
2½ "	1	1	1	1¼	1½	1¾	1¾	. . .	. . .
3 "	1	1	1	1¼	1½	1¾	2	2¼	. . .
4 "	1	1¼	1¼	1½	1½	1¾	2	2½	2½
8 "	1	1¼	1¼	1½	1¾	2	2¼	2¾	3
12 "	1	1¼	1½	1¾	2	2¼	2½	3	3¼
20 "	1	1½	2	2	2	2½	3	3¼	3½

ts longer than 20 inches and larger than 1¼ inches in diameter will be
led about 3 times the diameter of the rod.

WEIGHT OF NUTS AND BOLT-HEADS IN POUNDS.

FOR CALCULATING WEIGHT OF EXTRA LONG BOLTS.

n. Bolt in Inches.	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2½	3
ht of—													
onal nut and head.	.017	.057	.128	.267	.43	.73	1.10	2.14	3.78	5.6	8.7	17.	29.
" "	.021	.069	.164	.320	.55	.88	1.31	2.56	4.42	7.0	10.5	21.	36.
h of bolt, additional	.015	.03	.054	.085	.121	.165	.22	.34	.48	.66	.88	1.36	1.98

WEIGHT AND SIZE OF CAST WASHERS.

WEIGHT PER 100.

Bolt or Rod . .	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.
Dimensions .	1½ x 5/16	2 x ⅜	2½ x ½	3 x ⅝	3½ x ¾	4 x ⅞
Weight . . .	9½ lbs.	21 lbs.	43 lbs.	70 lbs.	113 lbs.	175 lbs.
Bolt or Rod . .	1⅛ in.	1¼ in.	1⅜ in.	1½ in.	1¾ in.	2 in.
Dimensions .	4½ x 1	5 x 1⅛	5½ x 1¼	6 x 1⅜	7 x 1½	7½ x 1⅝
Weight . .	256 lbs.	332 lbs.	455 lbs.	610 lbs.	865 lbs.	1,115 lbs.

STANDARD MACHINE SCREWS.

No.	Threads per Inch.	Diam. of Body.	Diam. of Flat Head.	Diam. of Round Head.	Diam. of Filister Head.	Len
						From
2	48, 56, 64	.0842	.1631	.1544	.1332	3-16
3	48, 56	.0973	.1894	.1786	.1545	3-16
4	32, 36, 40	.1105	.2158	.2028	.1747	3-16
5	32, 36, 40	.1236	.2421	.2270	.1985	3-16
6	30, 32, 36	.1368	.2684	.2512	.2175	3-16
7	30, 32	.1500	.2947	.2754	.2392	¼
8	30. 32, 36	.1631	.3210	.2936	.2610	¼
9	24, 30, 32	.1763	.3474	.3238	.2805	¼
10	24, 30, 32	.1894	.3737	.3480	.3035	¼
12	20, 24	.2158	.4263	.3922	.3445	⅜
14	18, 20, 24	.2421	.4790	.4364	.3885	⅜
16	16, 18, 20	.2684	.5316	.4866	.4300	⅜
18	16, 18, 20	.2947	.5842	.5148	.4710	½
20	16, 18	.3210	.6368	.5690	.5200	½
22	16, 18	.3474	.6894	.6106	.5557	½
24	14, 16, 18	.3737	.7420	.6522	.6005	½
26	14, 16	.4000	.7420	.6938	.6425	¾
28	14, 16	.4263	.7946	.7354	.6920	⅞
30	14, 16	.4520	.8473	.7770	.7240	1

WOOD SCREWS.

Diameter = number × 0.01325 + 0.056.

No.	Diam.	No.	Diam.	No.	Diam.	No.	Diam.	No.
0	.056	6	.135	12	.215	18	.293	24
1	.069	7	.149	13	.228	19	.308	25
2	.082	8	.162	14	.241	20	.321	26
3	.096	9	.175	15	.255	21	.334	27
4	.109	10	.188	16	.268	22	.347	28
5	.122	11	.201	17	.281	23	.361	29
								30

WOOD SCREW TEST.

(SCREWS DRAWN OUT OF YELLOW PINE.)

Screw.	½ in.	⅝ in.	¾ in.	⅞ in.	1
Wood, deep...	3½ in.	4 in.	4 in.	5 in.	6
At lbs..........	4,960	6,000	7,685	11,500	1

SPIKES, NAILS AND TACKS.

STANDARD STEEL WIRE NAILS.						STEEL WIRE SPIKES.			COMMON IRON NAILS.		
		Common.		Finishing.							
Sizes.	Length.	Diam. inches.	No. per pound.	Diam. inches.	No. per pound.	Length.	Diam. inches.	No. per pound.	Size.	Length.	No. per lb.
2d	1″	.0524	1060	.0453	1558	3″	.1620	41	2d	1″	800
d	1¼″	.0588	640	.0508	913	3½″	.1819	30	3d	1¼″	400
d	1½″	.0720	380	.0508	761	4″	.2043	23	4d	1½″	300
	1¾″	.0764	275	.0571	500	4½″	.2294	17	5d	1¾″	200
	2″	.0808	210	.0641	350	5″	.2576	13	6d	2″	150
	2¼″	.0858	160	.0641	315	5½″	.2893	11	7d	2¼″	120
	2½″	.0935	115	.0720	214	6″	.2893	10	8d	2½″	85
	2¾″	.0963	93	.0720	195	6½″	.2249	7½	9d	2¾″	75
	3″	.1082	77	.0808	137	7″	.2249	7	10d	3″	60
	3¼″	.1144	60	.0808	127	8″	.3648	5	12d	3¼″	50
	3½″	.1285	48	.0907	90	9″	.3648	4½	16d	3½″	40
	4″	.1620	31	.1019	62	. .	. .	. .	20d	4″	20
	4½″	.1819	22	. .	. .	. .	. .	. .	30d	4½″	16
	5″	.2043	17	. .	. .	. .	. .	. .	40d	5″	14
	5½″	.2294	13	. .	. .	. .	. .	. .	50d	5½″	11
	6″	.2576	11	. .	. .	. .	. .	. .	60d	6″	8

TACKS.

	Length. in.	Number per pound.	Title. oz.	Length. in.	Number per pound.	Title. oz.	Length. in.	Number per pound.
	⅛	16000	4	7/16	4000	14	13/16	1143
	3/16	10666	6	9/16	2666	16	⅞	1000
	¼	8000	8	⅝	2000	18	15/16	888
	5/16	6400	10	11/16	1600	20	1	800
	⅜	5333	12	¾	1333	22	1 1/16	727
						24	1⅛	666

WROUGHT SPIKES

Number to a keg of 150 lbs.

th.	1-4 inch. No.	5-16 inch. No.	3-8 inch. No.	Length. In.	1-4 inch. No.	5-16 inch. No.	3-8 inch. No.	7-16 inch. No.	1-2 inch No.
	2250	. .	.	7	1161	662	482	445	306
½	1890	1208	. .	8	. .	635	455	384	256
	1650	1135	. .	9	. .	573	424	300	240
½	1464	1064	. .	10	. .	. .	391	270	222
	1380	930	742	11	. .	. .	. .	249	203
	1292	868	570	12	. .	. .	. .	236	180

CHAPTER XXVIII.

STRENGTH OF MATERIALS.

Strength of Cast Iron.—When a specimen of cast
cross-section is one square inch is pulled apart, as, fo
by supporting it at one end and hanging weights from
the number of pounds necessary to pull it asunder va
with different specimens, as will be seen from the follo
An average safe value is 18,000 pounds per square inc

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF CAST-IRON.

	Breal a sq
Common pig-iron, ...	
Good common castings, ...	
Cast-iron "	
" "	
" "	
Gun-heads, specimen from, ...	
" " "	
Greenwood cast-iron, ...	
" " (after third melting,) . .	
Mean of American cast-iron, ...	
Gun-metal, mean, ...	

When subjected to a crushing force cast-iron offer
greater resistance than it does to tension. The crus
alled its ultimate compressive strength, varies from
00 pounds per square inch, and a fair averag
unds. On account of its cheapness it is la
parts of machinery which are subjected
but comparatively small tensile

'astings.—Iron and some of the other metals, like brass, lead, ;, and tin, can be cast in moulds. On cooling they shrink, and wance must be made for this. The following tables will be 'ul for this purpose:

TABLE

OWING THE WEIGHT OF CASTINGS BY WEIGHT OF THE PATTERNS.

ultiply the weight of the pattern by the multiplier opposite ı material.

White Pine	× 16	Cast-iron.
“	× 17·1	Wrought-iron.
“	× 17·3	Steel.
“	× 18	Copper.
“	× 25	Lead.

TABLE

SHOWING THE SHRINKAGE OF CASTINGS OF DIFFERENT METALS.

-iron, $\frac{1}{8}$ inch per lineal foot.	Tin, $\frac{1}{12}$ inch per lineal foot.
ss, $\frac{3}{16}$ “ “	Zinc, $\frac{5}{16}$ “ “
d, $\frac{1}{8}$ “ “	

ule *for finding the approximate weight of iron castings from pat-s.*—Multiply the weight of the pattern by the figures corre-ıding to the material in the table. Very accurate results can-be expected, as the specific gravity of wood as well as of iron es.

Pine wood	14·0
Oak “	9·0
Beech “	9·7
Linden “	13·4
Birch “	10·6
Alder “	12·6
Pear-tree wood	10·0

'rength of Wrought-iron.—The tensile strength of wrought-iron, while much larger than that of cast iron, varies almost as much with different specimens as that of cast iron, as will be seen in the table. Good wrought iron should exhibit a tensile breaking strength, however, of about 50,000 pounds per square inch.

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF AMERICAN WROUGHT-IRON.

	Breaking weight of a square inch bar.
From Salisbury, Conn.,	66,000
“ Pittsfield, Mass..	57,000
“ Bellefonte, Pa.,	58,000
“ Maramec, Mo.,	43,000
“ “ “	53,000
“ Centre County, Pa.,	58,400
“ Lancaster County, Pa.,	58,061
“ Carp River, Lake Superior,	89,582
“ Mountain, Mo., Charcoal bloom,	90,000
American hammered,	53,900
Chain-iron,	43,000
Rivets,	53,300

Its compressive strength is about the same as its tensile strength. An important point in the testing of iron and steel with a view to determining their quality, is the amount of elongation the test piece will stand before it breaks. Good wrought iron should show an elongation of 18 to 25 per cent.

Strength of Steel.—The tensile and compressive strengths of steel may be made to vary from 50,000 to 200,000 pounds per square inch by altering the percentage of carbon and other materials in its composition. Mild steel for boilers is usually specified to be between 55,000 and 65,000 pounds per square inch tensile strength, and to show an elongation before breakage of 20 to 27 *per cent.*

The variations in tensile strength of various kinds of steel may *seen* in the table below.

	Breaking weight of a square inch bar.
	52,250
lates,	50,000
boiler-plates,	55,000
joints, double-riveted,	35,000
" single "	28,600
steel, highest strength,	198,910
" lowest "	163,760
" average "	180,000
neous metal,	105,732
" 2d quality,	81,663
r steel,	148,324
"	154,825
"	157,881

TENSILE STRENGTH OF METALS.

Name of Metal.	Tensile Strength in pounds per sq. in.
ım wire,	30,000–40,000
re, hard-drawn,	50,000–150,000
phosphor, hard-drawn,	110,000–140,000
silicon "	95,000–115,000
wire, hard-drawn,	60,000–70,000
re,	38,000–41,000
st,	13,000–29,000
ire, hard-drawn,	80,000–120,000
" annealed,	50,000–60,000
ıst or drawn,	26,000–33,000
ım	39,000
n, wire,	50,000
ire	42,000
ild, hard-drawn,	100,000–200,000
ırd, "	150,000–330,000
t or drawn,	4000–5000
st,	7000–13,000
awn,	22,000–30,000

TENSILE STRENGTH OF DIFFERENT KINDS OF WOOD.

	Lbs. per Sq. Inch.		] {
Alder	14,000	Hickory	
Ash	16,000	Lignum-Vitæ	
Birch	15,000	Larch	
Baywood	12,000	Locust	
Beech	11,500	Maple	
Bamboo	6,000	Mahogany	
Boxwood	20,000	Oak	
Cedar	7,000	Pear	
Chestnut	13,000	Pine	
Cypress	6,000	Poplar	
Elder	10,000	Sycamore	
Elm	6,000	Teak	
Fir or Spruce	10,000	Walnut	
Hazel	18,000	Yew	
Holly	16,000		

SHOWING THE AVERAGE CRUSHING LOAD OF DIFFERENT MATER
OR THE WEIGHT UNDER WHICH THEY WILL CRUMBLE.

	Lbs. per Sq. Inch.		Lbs. per S
Alder	6,900	Walnut	
Ash	8,600	Willow	
Beech	7,600	Slate	1
Cedar	5,700	Sandstone	
Elm	10,000	Limestone	1
Fir—Spruce	6,500	Concrete	
Hickory (white)	8,925	Zinc	
Hornbeam	4,500	Copper, cast	2
Larch	3,200	Brass "	1
Locust	9,113	Tin	1
ple	8,150	Lead	
	4,200	Hard brick	
lish	6,500	Crown glass	3
h)	6,800	Granite, Eng.	1
yellow	5,300	Portland cement	
	5,100	Freestone, Conn.	
	3,700	Marble, Am	1

are about the highest values that are obta
ng about two-thirds to three-quarters of

TABLE SHOWING SIZE, WEIGHT, &c., OF WIRE.

Number by Wire Gauge.	Diameter in Decimals of 1 inch.	Feet to the pound.	Weight of 1 foot, in pounds.	Weight of 1 mile, in pounds.	Length of 1 bundle (63 lbs.), in yards.	Area of section, in decimals of 1 square inch.	Actual breaking weig't of bright market wire, in lbs.	Tensile strength of bright market wire per square inch of section, in lbs.
00000	.450	1.863	.5366	2833.248	39.12	.15904	12,598	78,903
0000	.400	2.358	.4240	2238.878	49.52	.12566	9,955	79,326
000	.360	2.911	.3435	1813.574	61.13	.10179	8,124	79,813
00	.330	3.465	.2886	1523.861	72.77	.08553	6,880	80,437
0	.305	4.057	.2465	1301.678	85.20	.07306	5,926	81,110
1	.285	4.645	.2153	1136.678	97.55	.06379	5,226	81.925
2	.265	5.374	.1861	982.555	112.85	.05515	4.570	82,873
3	.245	6.286	.1591	839.942	132.01	.04714	3,948	83,756
4	.225	7.454	.1342	708.365	156.53	.03976	3,374	84,862
5	.205	8.976	.1114	588.139	188.50	.03301	2,839	86,000
6	.190	10.453	.09566	505.084	219.51	.02835	2,476	87,349
7	.175	12.322	.08115	428.472	258.76	.02405	2,136	88,802
8	.160	14.736	.06786	358.3008	309.46	.02011	1,813	90,153
9	.145	17.950	.05571	294.1488	376.95	.01651	1.507	91,276
10	.130	22.333	.04477	236.4384	468.99	.01327	1,233	92,890
11	.1175	27.340	.03658	193.1424	574.14	.01084	1,010	93,194
12	.105	34.219	.02922	154.2816	718.60	.00866	810	93,530
13	.0925	44.092	.02268	119.7504	925.93	.00672	631	93,917
14	.080	58.916	.01697	89.6016	1237.24	.00503	474	94,299
15	.070	76.984	.01299	68.5872	1616.66	.00385	372	96,703
16	.061	101.488	.00985	52.008	2131.25	.00292	292	99,922
17	.0525	137.174	.00729	38.4912	2880.65	.00216	222	102,740
18	.045	186.335	.00537	28.3378	3913.04	.00159	169	106,343
19	.040	235.084	. . .	22.3872	4936.76	.0012566	137	109,362
20	.035	308.079	. . .	17.1389	6469.66	.0009621	107	111,184

HOISTING ROPES (19 WIRES TO THE STRAND).

	IRON.							CRUCIBLE STEEL.			
Trade Number	Diameter in ins.	Circumference in inches.	Weight per foot, in lbs., with hemp center.	Breaking Stress, in Tons of 2,000 lbs.	Proper Working Load, in Tons of 2,000 lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave, in ft.	Breaking Stress, in Tons of 2,000 lbs.	Proper Working Load, in Tons of 2,000 lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave in feet.
1	2¼	7	8.	74	15	15½	8	164.69	32.9	.	9
2	2	6¼	6.3	65	13	14½	7	132.37	26.5	.	8
3	1¾	5½	5.25	54	11	13	6½	108.13	21.63	.	7½
4	1⅝	5	4.1	44	9	12	5	97.17	19.44	. . .	6
5	1½	4¾	3.65	39	8	11½	4¾	86.38	17.3	16½	5½
5½	1⅜	4¼	3.	33	6.5	10¼	4½	61.00	12.2	15	5
6	1¼	4	2.5	27	5.5	9½	4.-	50.17	10.	12¼	[illegible]
7	1⅛	3½	2.	20	4.	8	3½	38.00	7.7	11	4½
8	1	3⅛	1.58	16	3.	7	3	29.2	5.8	9½	4
9	⅞	2¾	1.2	11.5	2.5	6	2¾	21.55	4.	8	3¾
10	¾	2⅜	.88	8.64	1.75	5	2½	14.99	3.	6½	3½
10¼	⅝	2	.7	5.13	1.25	4½	2	12.53	2.5	5¾	3
10½	9/16	1¾	.44	4.27	.75	4	1¾	8.81	1.75	5¼	2¾
10¾	½	1½	.35	3.48	.5	3½	1½	7.52	1.5	4¾	2

CHAINS.

WEIGHT AND PROOF STRENGTH OF CHAIN MANUFACTURED BY THE NEW JERSEY STEEL AND IRON COMPANY.

STUD CHAIN.			SHORT LINK CHAIN.			X. B. CRANE CHAIN.
Size.	Average Weight per fathom.	Proof.	Size.	Average Weight per fathom.	Proof.	Proof.
Inches.	Pounds.	Tons.	Inches.	Pounds.	Tons.	Tons.
3/4	33	10	3/16	2 1/4	1/4	. . .
13/16	38	12	1/4	5	1/2	. . .
7/8	43	14	5/16	7	1	. . .
15/16	50	16	3/8	9 1/2	2	3
1	58	18	7/16	12	2 1/2	4
1 1/16	65	20	1/2	15	3 1/2	4 1/2
1 1/8	72	23	9/16	19	4 1/2	5 1/2
1 3/16	80	26	5/8	25	5 1/2	7
1 1/4	88	28	11/16	30	7	8 1/2
1 5/16	98	31	3/4	35	8	10
1 3/8	110	34	13/16	40	9 1/2	11 1/2
1 7/16	114	37	7/8	47	11	13
1 1/2	127	41	15/16	54	12 1/2	14 1/2
1 9/16	138	44	1	61	14	16
1 5/8	150	48	1 1/16	69	16	19
1 11/16	157	52	1 1/8	76	18	21
1 3/4	170	56	1 3/16	85	20	23
1 13/16	184	60	1 1/4	95	22	25
1 7/8	200	64	1 5/16	103	24	27
1 15/16	214	68	1 3/8	113	26	29
2	230	72	1 7/16	123	28	31
2 1/8	250	80	1 1/2	133	30	33
2 1/4	290	88				

GALVANIZED WIRE ROPES, FOR SHIPS' RIGGING, GUYS FOR DERRICKS, &c.

TRENTON IRON CO.'S LIST.

Circumference in inches.	Weight, per fathom, in lbs.	Circumference of Hemp Rope of equal strength, in ins.	Breaking Stress, in tons of 2,000 lbs.	Circumference in inches.	Weight, per fathom, in lbs.	Circumference of Hemp Rope of equal strength, in ins.	Breaking Stress, in tons of 2,000 lbs.
5 1/2	26 1/2	11	43	3	8	6	12
5 1/4	24 1/2	10 1/2	40	2 3/4	6 3/4	5 1/2	10
5	22	10	35	2 1/2	5 1/2	5	8 1/2
4 3/4	20 1/2	9 1/2	33	2 1/4	4 1/4	4 1/2	7
4 1/2	18	9	30	2	3 1/2	4	6
4 1/4	16	8 1/2	26	1 3/4	2 1/2	3 1/2	5
4	14 3/4	8	23	1 1/2	2	3	3 1/2
3 3/4	12	7 1/2	20	1 1/4	1 1/2	2 1/2	2 1/2
3 1/2	10 3/4	7	16	1	3/4	2	2
3 1/4	9 1/2	6 1/2	14	7/8	1/2	1 1/2	1

·ength of rope will be found under the chapter on **transmis-** ›f power.

ctors of Safety.—In making use of tables on the strength .terials engineers do not make the size of the piece just large ;h to support its load, but make it several times larger, so as on the safe side. The number of times larger depends on ature of the load to which it is to be subjected, and is called ctor of safety. The following represent good practice: Where ›ad is steady with no vibration, such as in roofs, the factor ety is 3. Where load is fairly uniform but causing vibration, shafting hung from roof, the roof material sizes would be cal- ›d with a factor of safety of 4.

ıen the load is reversed in direction the factor is 6.

ams—Wooden.—The load which a beam will support de- ı upon its depth, width, length between points at which it is ›rted, the kind of wood and the way in which it is loaded. A is uniformly loaded when the weight per square inch rest- n and supported by it is the same at all parts of its length. am so loaded will support more pounds than if the weight all concentrated and hung from a hook in the middle.

e table on the opposite page, taken from the Carnegie hand- , is calculated with a factor of safety of 4:

the load is suspended from one point between the points of ›rt of the beams, the safe load may be taken as one-half that ı in the table.

ample.—Suppose it is desired to lift an engine fly-wheel ıing 1500 pounds by a block and tackle suspended from a en beam. The beam supports only a light floor and is itself ›rted by the walls of the building, the distance between the s of support being 12 feet deep. The beam is 12″ deep by de, of white pine. Will it safely support the pulley, and by nuch margin?

om the table a beam 12 feet long, 12″ deep, and 1″ wide uni- y loaded will *support* 1000 pounds with a factor of safety of *oaded at one point its* safe load will be 500 pounds. Therefore a 4″ beam will support 2000 pounds, and if the pull were to be attached to an eye-bolt screwed into the beam, si the eye-bolt would be about ¾″ diameter, and would take ¾″ fr the width of the beam, this beam would just do the work safel

SAFE LOADS, UNIFORMLY DISTRIBUTED, FOR RECTANGULA SPRUCE OR WHITE PINE BEAMS.

ONE INCH THICK.

Calculated with factor of safety = 4.
(For oak, increase values in table by ⅓.)
(For yellow pine, increase values in table by ⅔.)

Span in feet.	DEPTH OF BEAM.										
	6″	7″	8″	9″	10″	11″	12″	13″	14″	15″	16″
5	600	820	1070	1350	1670	2020	2400	2820	3270	3750	4270
6	500	680	890	1120	1390	1680	2000	2350	2730	3120	3560
7	430	580	760	960	1190	1440	1710	2010	2330	2680	3050
8	380	510	670	840	1040	1260	1500	1760	2040	2340	2670
9	330	460	590	750	930	1120	1330	1560	1810	2080	2370
10	300	410	530	670	830	1010	1200	1410	1630	1880	2130
11	270	370	490	610	760	920	1090	1280	1490	1710	1940
12	250	340	440	560	690	840	1000	1180	1360	1560	1780
13	230	310	410	520	640	780	930	1080	1260	1440	1640
14	210	290	380	480	590	720	860	1010	1170	1340	1530
15	200	270	360	450	560	670	800	940	1090	1250	1420
16	190	260	330	420	520	630	750	880	1020	1180	1330
17	180	240	310	400	490	590	710	830	960	1100	1260
18	170	230	290	370	460	560	670	780	910	1040	1190
19	160	210	280	360	440	530	630	740	860	990	1130
20	150	200	270	340	420	510	600	710	820	940	1070
21	140	190	260	320	390	480	570	670	780	890	1020
22	140	190	240	310	380	460	540	640	740	850	970
23	130	180	230	290	360	440	520	610	710	810	920
24	130	170	220	280	350	420	500	590	680	780	890
25	120	160	210	270	330	410	480	560	660	750	860
26	110	160	210	260	320	390	460	540	630	720	820
27	110	150	200	250	310	370	440	520	610	690	790
28	110	140	190	240	300	360	430	500	580	670	760
29	110	140	180	230	290	350	410	490	560	640	740

To obtain the safe load for any thickness: **Multiply values for 1 inch by thickness of beam.**

To obtain the required thickness for any load: **Divide by safe load for 1 inch.**

he table under bolts gives some tests showing how many ds weight is necessary to pull out screws from yellow pine. table shows that a ¾″ screw sunk 5″ into the wood required 5 pounds to pull it out. Using a factor of safety of 4, this ld support nearly 1900 pounds, or 400 pounds more than the unt of its load.

teel beams are made with a shape like the letter I, and are e called I beams. The top and bottom pieces are called the ges and the vertical piece running between and connecting them lled the web. By the table on p. 654 taken from the catalogue e Stillwell-Pierce & Smith-Vaile Company, we can calculate t load a beam will carry if uniformly loaded, using a factor fety of 4. If the load is concentrated at one point, only one- the result given by the table should be used.

xample.—What load at its centre can be safely suspended from I beam whose thickness of web is .23 and whose flanges are wide, if the span between points of support is 10 feet? From able the coefficient for a 6″ beam of these dimensions is 83,500. iding this by 10 we get 8,350 pounds as the safe distributed , and half this, or 4175 pounds, can be suspended at one point.

uniformly loaded beam has the greatest tendency to break s middle point, and a smaller weight will break a beam if ied at its middle than at any other point. So that the ex- les given above as applying to a weight suspended at any t are not strictly correct; but as they are on the safe side greatly simplify the calculations, it was considered best to them in this shape.

olumns.—The values for crushing or compressive strength n in the tables are not safe to use where the length of the subjected to the crushing force is more than four times its eter, as with longer pieces a bending action comes in which es them to give way long before the load given in the tables ached. The calculation of sizes of columns is beyond the e of *this book, but will* be found in treatises on applied me- *ics and strength of* materials.

TABLE,

Giving the size, weight, and safe load that the Carnegie Stee I Beams will carry with the load equally distributed.

No. of Shaft.	Depth of Beam.	Thickness of Beam.	Width of Flange in Inches.	Weight per Foot.	Coefficient of Strength for One Beam.
301 b	20	0.60	7.	80	1,545,60
301 d	20	0.50	6.250	64	1,222,40
302 c	15	0.78	6.125	80	1,103,20
302 b	15	0.45	5.75	50	753,30
302 d	15	0.40	5.50	41	603,20
303 b	12	0.39	5.50	40	500,10
303 d	12	0.35	5.25	32	395,20
304 b	10	0.37	5.00	33	344,00
304 d	10	0.32	4.75	25.5	263,8
305 b	9	0.31	4.75	27	262,2
305 d	9	0.27	4.50	21	199,9
306 b	8	0.27	4.50	22	191,6
306 d	8	0.25	4.25	18	154,0
307 b	7	0.27	4.25	20	151,4
307 d	7	0.23	4.00	15.5	117,6
308 b	6	0.26	3.62	16	101,8
308 d	6	0.23	3.50	13	83,5
309 b	5	0.26	3.12	13	67,0
309 d	5	0.22	3.00	10	52,9
310 b	4	0.24	2.75	10	41,2
310 d	4	0.20	2.62	7.5	31,4

QUESTIONS.

some of the important properties of metals.
e specific gravity.
would you obtain the specific gravity of a piece of brass?
of a piece of wood?
metal is most useful on account of its malleability?
on account of its ductility?
out what temperature does iron melt?
h would be used in a piece of iron subject to tension—
wrought iron?
effect on the strength of steel does an increase in the per-
of carbon have?
effect upon its ductility?
is a factor of safety?
factor is ordinarily used where the load is a steady one?
cannot the tables for crushing strength be used in long
?
the atomic weights and chemical equivalents of the dif-
etals in use at the present day.
h is the most useful metal?
the weight of a cubic foot of wrought-or cast-iron.
the component parts of cast-iron.
at two elements is steel composed?
the heat-conducting properties of copper, brass, cast- and
-iron.
e tensile strength.
the tensile strength of copper, brass, gun-metal, wrought-
-iron.
does the tensile strength of wrought-iron compare with its
sive strength?
the proportions of carbon in the various grades of iron
l.
the *different proportions* of the metals which form the basis
Muntz metal, gun-metal, Babbitt metal, and bronze alloy.

Give the composition of fusible metal which melts at a temp ture of 212° Fah.

Give the rule for finding the approximate weight of iron ings from the weight of the pattern.

Give the shrinkage various metals undergo in the proce casting.

Give the weight and bulk of several substances in cubic pounds, and tons.

Give the extension of wrought- and cast-iron at various peratures.

Does wrought-iron increase in strength up to a certain perature?

Is the tensile strength of copper increased by the applic of heat?

Give the composition of a good non-conductor for preve radiation of heat in steam-boilers, cylinders, pipes, etc.

For what is lead principally used in electrical work?

What are some of its other uses?

How does it compare in weight with iron?

What is the melting-point of lead?

Why is it used for water pipes?

What is an I beam?

Which part is the web?

Which part is the flange?

PART IX.

ELECTRICITY.

CHAPTER XXIX.

NDAMENTAL EXPERIMENTS, PROPERTIES, AND UNITS.

ARIED as is electrical apparatus, and wide as are its uses, a simple experiments contain the germs or fundamental princi- on which such apparatus depends. If a plate of zinc and late of carbon be immersed in a solution of chromic acid, iout touching each other, and if now they are connected by ins of two wires, preferably of copper, one attached to each, e very peculiar effects can be observed.

xperiment 1.—The wire connecting them will be heated. If e short, it will be heated more than if it is long, and if it of a size about No. 18 and only a few inches long, it will ome quite hot.

xperiment 2.—If a compass-needle or a bar-magnet be ught near the wire, the magnet will tend to assume a direc- crosswise to the length of wire. This tendency is manifested ny point along the length of wire.

xperiment 3.—If we separate the wires from each other and them into a solution of copper sulphate, one of the wires, that ched to the carbon plate, will gradually be eaten away, while other will increase in size by an equal amount owing to allic copper depositing upon it. There appears to be set up urrent of something which takes the copper from one wire *ed the anode to the* other called the cathode.

This current we call the electric current, and though produ in the above experiments by the action of chromic acid on in the presence of carbon, there are many other ways of produc it. Wherever chemical action is used to produce electrical rent the apparatus is called a battery. Other plates than and carbon and other solutions than chromic acid may be u Zinc, however, is usually employed for one of the plates. solution must be one capable of strongly attacking zinc, some strong acid is usually employed.

If in Experiment No 3, we should change the wires so tha one formerly connected to zinc was now connected to coppe should find that the overgrown wire would be reduced in size copper would be deposited on the eaten wire. The current dently flows from the carbon plate to the zinc plate. This ex ment, then, will enable us to determine in what direction a cu is flowing in any circuit, for we can run wires from the term of the electric generator into a solution of copper sulphat almost any soluble salt of a metal) and note on which wire n is deposited.

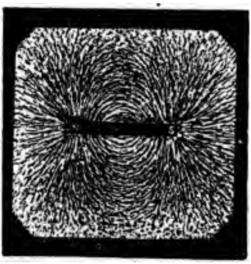
Another method of doing this is by means of the com needle or any freely suspended magnet. The north-seeking will always, if you imagine yourself swimming with the cu and facing so as to look at it, move toward your left.

The effect on the needle becomes very much stronger i wire is coiled around and placed with the compass-need its axis. When this is done the force acting on the need proportional to the number of turns in the coil.

Galvanometer.—A coil of wire with its terminals connect convenient binding-posts, and having mounted in its axis a fi suspended small magnetic needle, is used for detecting and measuring currents, and is called a galvanometer. If, for e ple, we wanted to find whether a combination of a zinc p a copper plate, and a solution of sulphuric acid would pro *electric* current, we would connect by a copper wire g-post of the galvanometer to the zinc plate and the he copper plate and see if the needle were moved. If so, we uld know that an electric current was produced, and by the ount of the movement we should judge of the strength of rent. Experiment 2 therefore contains the germ of current- asuring instruments as well as chemical electrical generators. periment 1 is evidently the basis for the modern electric heat- device and also of another class of current-measurements. e third experiment is the foundation of electro-plating and tro-metallurgy.

xperiment 4.—Suppose we connect a coil of wire by ans of pieces of wire to a galvanometer some distance away l then suddenly bring a strong magnet near the coil: the needle he galvanometer will give a sudden jump and will finally come rest after the motion of the magnet ceases. This shows that moving a magnet and a coil of wire relatively to each other electric current is produced, lasting only while the motion is ng on. It makes no difference which is moved, the magnet or coil, or both, provided the distance between them is changed, current will be produced during motion. If the motion be the opposite direction, the motion of the needle will be reversed, wing that the direction of the current is reversed. A current duced in this manner has all the properties of a current proced by chemical action, such as heating, decomposing chemical utions, depositing metals from solutions, etc., and is identical h it. This experiment contains the germ of the dynamo, which all its varied forms consists of a magnet or magnets and a coil coils, moving relatively to each other.

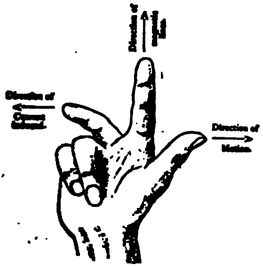
Lines of magnetic force, or lines of force more briefly, are lines in the direction of which magnetic force acts, and they the lines along which a very short magnet will set itself if magnet is absolutely free to move. The positive direction is direction which a free north-seeking pole would take. Every gnet, of course, exerts force on a magnet near it, and the space ound a magnet where this force is exerted is called its field. *very neat and easy* method of observing the nature of the field of a bar-magnet is to place the magnet under a piece of oi window-glass and scatter iron filings on the top side. T gently tapping the glass the filii assume the appearance shown figure. The filings, which ar magnets, set themselves in the di of the lines of force and map field. Notice that the lines are at the ends or poles of the i showing that the strength of the or intensity of the field is gre this point. If, as in Experim coil of wire were brought near this magnet, the wires wo across the lines of force, so that we say that *wherever a co cuts lines of magnetic force an electric pressure will be produ*



We know by experiment that the pressure produced is tional to the rate of cutting—*i. e.*, the number cut per sec

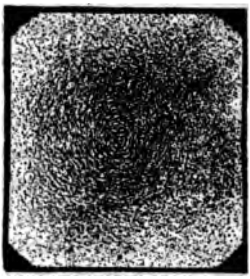
The direction of the induced current depends up relative direction of the lines of force and the motion of t ductor. A very neat rule for finding in what direction tl rent will flow is due to Prof. Fleming.

Point the forefinger along the positive direction of the m lines and point the thumb stret right angles in the direction in the conductor moves. If now t ond finger be stretched at right to both thumb and forefinger, point in the direction of the i current.



When the moving wire is shape of a coil, another rule is more convenient. Looking alo tion of the lines of force, if, owing to the mot mber enclosed by it diminishes, the curre oil right-handed; if the number of line ased, the current will flow around left-handed; and if there is change in the number of lines enclosed there will be no cur- it induced.

Lines of Force due to a Current.—Experiment No. 1 shows it there are lines of force around a wire carrying current, and we carry a wire through a piece of ss and sprinkle iron filings on the ss they will settle in circles centred h the wire, as shown in the figure.



Experiment 5.—If current from a ttery or dynamo be led through wire led around a piece of iron, the iron omes strongly *magnetized*, as we say; it is, it exhibits the properties of nagnet, attracting other pieces of n, and having polarity, one pole attracting the north-seeking le of a compass-magnet and the other repelling it. Such a gnet, which loses practically all its strength when current is pped, is called an electro-magnet, and is used in all or nearly electrical apparatus where a magnet is needed, it being possible produce a much stronger electro-magnet of a given size than ı be done with a permanent steel magnet.

Experiment 6.—Suppose that a coil of wire through which electric current passes is suspended so that it turns freely and nagnet is held near it. The coil will turn and move toward or ay from the magnet, according to which pole is held toward it. the coil is mounted so that its only possible motion is to revolve out one of its diameters as an axis, it will turn into a certain sition and then stop there. If at that moment the other pole the magnet is presented to it, or better, if the direction of rrent through the coil is reversed, the coil will rotate through other half turn, and if again the current is reversed, the coil ll keep on. Such a device when the current is automatically ersed at *just the right* time twice in each rotation of the coil is *lently an electric* motor.

Experiment [illegible].—Suppose we have the same coil of wir
[illegible] coil No. 1, connected
[illegible] attached to a bat
A [illegible] No. 2, but not through
No. [illegible] disconnect the battery
[illegible] galvanometer will give a su
[illegible] current through coil
a [illegible] as we say, in coil
[illegible] coil No. 2 in any way
[illegible] galvanometer will come t
[illegible] current has ceased
[illegible] No. 2 again, the needl
[illegible] opposite direction, sh
[illegible] direction. If the cu
[illegible] were diminished an
[illegible] first one way and th
[illegible] in the strength of c
[illegible] No. 1. Looked at
[illegible] the current in coil
[illegible] are enclosed by
[illegible] current is diminishe
[illegible] induced in the op
[illegible] each other the g
[illegible] introduced into the a
[illegible] enormously greater
[illegible] with a common iron
[illegible] principle than the m
[illegible]

[illegible] the length of th
[illegible] we shall be una
[illegible] If a galvan
[illegible] needle noted an
[illegible] the deflection
[illegible] that the current wa
[illegible] changed the g

arently the greater length of wire offers a greater resistance he flow of current, whence comes the idea that every electrical uit possesses resistance.

lectro-motive Force.—If now we should connect two batteries andem and connect their free terminals to the galvanometer, should find the deflection of the needle much greater than ore, which means that the flow of current is greater. One tery of a different type might produce a similar result. As resistance of the circuit is apparently not changed, but the v of current is much greater, reasoning by analogy from fluids should expect that there was such a thing as electrical pressure, l that the use of two batteries in tandem had increased it. The ctrical pressure which tends to force a current against the istance of a circuit is variously spoken of as *electric pressure, erence of potential, electro-motive force* (written *e. m. f.*), and *age.*

Units.—In order to deal intelligently with any substance or ce it has always been found necessary to have some means of asuring it. Thus with gas we want to know the quantity flow- per minute and its pressure; with water the same things; h gravity we want to know how much more it acts on one dy than on another. We therefore have to fix upon some venient standard of the substance or property we want to asure, and agree to call it a unit. For example, the unit of gth or distance is a certain carefully made standard rod ided into three parts, each of which we call a foot, and we asure all distances by seeing how many times a copy of this d is contained in the distance to be measured. The unit of ight is a certain carefully constructed weight, which we call pound, and all other weights are compared with this or with reful copies of it, and if a certain body is equal in weight to n of the standard we say its weight is ten pounds.

The common electrical properties which it is necessary to meas- e are current, *electro-motive* force (pressure), and resistance. *ving to the peculiarity* of these properties it is necessary to establish or agree on new units by which to measure them. Th names of these units have been taken from those of great discov erers in electrical science.

The unit of current is called the ampère, after a noted Frenc physicist, and it is that current which will in one second depo from a standard solution of silver nitrate .001118 gram (.01 grain) of silver on the cathode plate. This unit is a rate o flow, and is in its nature similar to a rate of 1 gallon of water p second.

Of course no one in measuring a current goes through the lo process of measurement by means of depositing a metal any mo than in order to measure a length he makes a journey to t British Museum to get the standard yard-stick. Convenie instruments working on the principle of a galvanometer a made so that when a current of one ampère flows through th coils their needle points to 1; with a current of 2 ampères, poi to 2, and so on.

The unit of electro-motive force or pressure is named the vol after an Italian scientist, Volta. It is the electrical pressure furnished by a certain kind of battery whose poles are zinc and mercury. [As a matter of fact the form of cell commonly used as a standard has an e. m. f. of 1.45 volts instead of 1 volt, but the definition of the unit is clearer if we assume that the standard cell gives exactly one volt.]

The unit of resistance, called the ohm, is the resistance of a column of mercury 41.85 inches long and weighing 223 grains at 32° F. The standard ohms for common use are made of wire instead of mercury, either German silver or an alloy of copper and nickel called platinoid being used.

The unit of power is named the Watt, after James Watt, and is equal to $\frac{1}{746}$ of one horse-power. A convenient multiple of this is called the Kilowatt, written K. W., and is equal to 1000 watts. Four horse-power are very nearly equal to 3 kilowatts, or 1 H. P. = $\frac{3}{4}$ K. W. very nearly.

***Multiples* of Units.**—Just as it is convenient to have multiples

, foot, such as a mile, rod, or inch, so in electrical work multi- of the above units are found useful. The following prefixes commonly used:

1 megohm = one million ohms;
1 microhm = " millionth part of 1 ohm;
1 kilowatt = " thousand watts.

he prefixes *meg*, *micro*, and *kilo* can be used with other units ı as above illustrated, but such use is somewhat rare.

aws of Resistance.—The resistance of a wire or conductor ənds on its length and the area of cross-section. The greater length the greater the resistance. The greater the cross-ion the *less* the resistance. Although this last is sometimes ıblesome to understand, it is quite analogous to the resistance red to the flow of water in a pipe; the greater the section of pipe the easier water flows through; that is, the *less* is the stance offered.

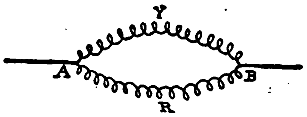
Ξxample.—A certain wire 10 feet long has a resistance of 2 ohms. ıat will be the resistance of 200 feet of it?

4ns.—20 × 2 = 40 ohms.

Example.—100 feet of wire $\frac{1}{10}''$ diam. have a resistance of 1 ohm. hat will be the resistance of 100 feet of the same kind of wire t having a diameter of $\frac{1}{20}''$?

4ns. Since the diameter is *one-half* as great, the area is *one-ırter* as great, therefore the resistance of the second wire is four ıes as great as that of the first.

Ͻonductivity is the reverse of resistance, and the conductivity a wire having a resistance of say 10 ohms is one-tenth, or one ided by whatever the resist-:e may be.



Ɩesistances in Multiple.—Two more wires are in multiple or ·allel when they *are connected* *hown in the figure.* To find the joint resistance from A to B when the resistance of one path is Y ohms and by the other R ohms.

The joint resistance from A to $B = \frac{R\,Y}{R + Y}$.

Example.—Two resistances of 10 ohms and 20 ohms are joi in multiple. What is their joint resistance?

Ans. $\frac{10 \times 20}{20 + 10} = \frac{200}{30} = 6\frac{2}{3}$ ohms.

With three resistances, having values of X ohms, Y ohms, R ohms each, connected in multiple, their joint resistance is

$$\frac{R\,X\,Y}{R\,X + R\,Y + X\,Y}.$$

Example.—Suppose three lamps having resistances of 200, 1 and 50 ohms respectively are connected in multiple. What their joint resistance?

Ans. $\frac{200 \times 100 \times 50}{200 \times 100 + 200 \times 50 + 100 \times 50} = \frac{1{,}000{,}000}{35{,}000} = 28.57$ oh

When, as in the case of incandescent lamps, the resistance each branch is the same, the joint resistance is equal to the re ance of one *divided* by the number of lamps.

Example.—A certain lamp has a resistance of 200 ohms. Wh would be the joint resistance of 200 of such lamps connected parallel?

Ans. $\frac{200}{200}$, or 1 ohm.

Resistances in Series.—When two resistances are placed tandem or series, their joint or total resistance is equal to the of their individual resistances.

Specific resistance is a term having the same relatio resistance as specific gravity has to weight. It is usually gi in microhms (millionths of an ohm) per cubic centimetre or ic inch. From a table of specific resistances and the law tion of resistance with length and cross-section, the tor may be calculated.

ble is taken from Ayrton.

TABLE OF RELATIVE RESISTANCES.

(Substances arranged in order of Increasing Resistance for same length and sectional area.)

Name of Metal.	Resistance in Microhms at 0° Centigrade. 32° Fahr.		Relative Resistance.
	Cubic Centimetre.	Cubic inch.	
Silver, annealed	1·504	0·5921	1
Copper, annealed	1·598	0·6292	1·063
Silver, hard drawn	1·634	0·6433	1·086
Copper, hard drawn	1·634	0·6433	1·086
Gold, annealed	2·058	0·8102	1·369
Gold, hard drawn	2·094	0·8247	1·393
Aluminium, annealed . . .	2·912	1·147	1·935
Zinc, pressed	5·626	2·215	3·741
Platinum, annealed	9·057	3·565	6·022
Iron, annealed	9·716	3·825	6·460
Gold-silver alloy (2 oz. gold, 1 oz. silver), hard, or annealed	10·87	4·281	7·228
Nickel, annealed	12·47	4·907	8·285
Tin, pressed	13·21	5·202	8·784
Lead, pressed	19·63	7·728	13·05
German silver, hard, or annealed	20·93	8·240	13·92
Platinum-silver alloy (1 oz. platinum, 2 oz. silver), hard, or annealed . . .	24·39	9·603	16·21
Antimony, pressed	35·50	13·98	23·60
Mercury	94·32	37·15	62·73
Bismuth, pressed	131·2	51·65	87·23
Carbon	. . .	. . .	14·

Non-conductors.—The metals generally have a fairly low cific resistance and are therefore classed as good conductors. n-metals have a high specific resistance, and are called non- ductors or insulators, and are used for supporting or covering res to prevent leakage of electrical currents from them.

The *following table gives* the approximate relative resistance *everal of them referred* to copper as a standard.

Copper	1.
Paper	300,000,000,000,000,000.
Porcelain	4,000,000,000,000,000,000.
Mica	14,000,000,000,000,000,000.
Flint glass	130,000,000,000,000,000,000.
Gutta percha	280,000,000,000,000,000,000.
Wood tar	1,000,000,000,000,000,000,000.
Shellac	5,600,000,000,000,000,000,000.
Ebonite	17,100,000,000,000,000,000,000.
Paraffin wax	20,000,000,000,000,000,000,000.

The above values for the resistance of insulators are only proximate, as their measured resistance will be different accord to the electrical pressure with which they are tested, higher me ured values being obtained when a small testing pressure is us Mineral oils are also very good insulators if they are prevent from absorbing moisture by being kept from contact with air.

Change in Resistance with Change in Temperature.—Th metals when heated *increase* in resistance, the percentage of i crease for each degree rise in temperature being equal for t same metal, although this percentage varies somewhat in t different metals. The following table gives the increase in res ance of 1 ohm for one degree rise in temperature, in the case some common metals.

Aluminum	.0022	Mercury	.0
Copper	.0025	Platinum	.0
German silver	.0001	Silver	.0
Iron	.0025	Tin	.0
Lead	.0022	Zinc	.0

Example.—A certain copper wire has at 60° F. a resistance 200 ohms. What will the resistance be at 100° F.?

Ans. $200 + .0025 \times 40 = 200 + .1 = 200.1$ ohms.

Non-conductors *diminish* in resistance as they are heated. Th *change* is much greater than with metals and much less regu *In the* case of carbon the change in resistance in 1 ohm is abo ? ohm per degree.

'ractical Use of Conductors and Insulators.—For carrying trical energy from the point where it is generated to the it where it is to be used we want to use such material and uch size that the resistance of the circuit does not exceed onable limits, although we must be guided by consideration he first cost. Copper has the lowest specific resistance of the mon metals and is generally employed, although if aluminum much lower in price than now (30 cts. per pound), it will be rious competitor to copper. Iron is used only on short tele-)h and telephone lines. It is evident that the circuit should s direct as possible, as the greater its length the greater its stance, and therefore the greater is the amount of energy lost he line.

nsulators are used to prevent current from being led off the luctors. For all work except outdoor work, and, indeed, for rge part of that, the conducting wire is covered with one or e layers of some compound of rubber which is a good insulator. thicker this rubber covering the better its insulating proper- for we have made the path of leakage of current longer by kening the rubber coating. A further protection is given by ending the wires at intervals on porcelain or glass or other lators, so that the wire only comes in contact with its coating, elain, or the air, which is also an exceedingly good insulator. um up briefly, make the path through which you want the ent to flow as short and easy as possible. Make all possible age paths as long and narrow as possible.

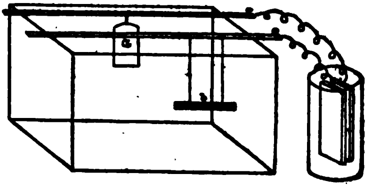
urrent Effects.—Heating.—The passage of current through conductor heats it by an amount depending on the resistance he conductor and the strength of the current. If we pass ugh a conductor having 10 ohms resistance a current of 10 ères and the same current through another conductor having hms resistance, the heat units developed in the latter will be ble the number produced in the former coil. This result, vn by repeated *experiment*, is of very great importance, and *pressed by saying that the heating effect is directly proportional* *to the resistance.* If the resistance is small, the heating is sm if the resistance is zero, the heating is zero.

If now through a conductor having 10 ohms resistance we a current of 10 ampères and measure the heating effect, an we next double the current, making it 20 ampères, we shall that the heating effect, instead of being *twice* as great, is *four* ti as great as before. With a current of 30 ampères the hea would be *nine* times as great. In other words, the *heating is proportional to the square of the current.* If a current ampères passes through a resistance of *R* ohms, the heating e —that is, the number of heat units produced per second .00096C^2R, or $C \times C \times R. \times .00096$.

The utilization of the heating effect of the electric curre seen in electric stoves, cooking utensils, car heaters, soldering i etc., etc. Wires carrying currents, if too small, may becom heated as to set fire to wood in the vicinity, and on this acc insurance underwriters have adopted a table showing the la current which different sized wires will safely carry.

Electrolytic Effects.—In Experiment No. 3 it was shown an electric current decomposes solutions of metallic salts deposits the metal on the cathode plate. One ampère will al deposit .017 grain of silver in one second, whether the solu be silver nitrate, silver sulphate, or any salt of silver. ampère will always deposit a definite quantity of gold in second whatever be the salt of gold used. This quantity depo in one second by a current of one ampère is called the ele chemical equivalent of the substance. Two ampères will de twice as much as one ampère in one second; three ampères, t times as much, and so on.

Electro-metallurgy.—The electrolytic effects of the ele current are employed practically in electro-plating either type-printing or for covering cheap metals like brass, cop iron, or German silver with one or more layers of nickel, sil or gold. The general method is to connect a suitable curr enerator, either a battery or low-pressure dynamo, to two es suspended in a tank containing a solution of some salt of the al we wish to deposit. The anode must be made of this same al, while the object to be ed is hung to the cathode. order to secure a tough, orm deposit it is neces- to have a certain rela- between the current igth and the number of ire inches of surface on object to be plated. For example:



Copper, in an acid solution,	about	3 ampères	per	100 sq.	inches.
Copper, in cyanide solution,	"	2 "	"	"	"
Zinc,		2 "	"	"	"
Silver,		2 "	"	"	"
Gold,		1 ampère	"	"	"
Brass.					
Nickel, at first 8 and diminish to		2 ampères	"	"	"

ressure Required.—Different baths require different pressures, ıay be seen in the following table:

er, acid	about 1.5 volts.	Silver	about 1 volt.
er, cyanide	" 4 "	Brass	" 4 volts.
l	" 2 "	Nickel	" 4 "

uantities Deposited in one Hour by One Ampere—

er	18 grains.	Nickel	15.5 grains.
l	35.5 "	Silver	62 "

electro-plating the object is first rinsed in a solution of stic potash to remove all grease, then rinsed in water to remove potash, and finally hung in the plating-bath. After a suf- ntly thick coat has been deposited it is taken out and rinsed ater and then dried and polished.

lectro-motive force, or electrical pressure, may be produced nany different ways, such as: (1) by rubbing two different stances together, as silk and glass; (2) by heating two different *ls which are joined* together; (3) by chemical action, as in the battery; (4) by moving a magnet relatively to a coil, the dynamo. Of these the last is the most common, beca has proved to be the most economical. The chemical m stands next in importance, being used where only small am of energy are needed.

When two points or objects are at different electric pre a current will flow from one to the other if a conductor is to connect them. This current will persist till enough elect has flown from the high pressure point to the lower to eq the pressure. Conversely, if we connect two points by a c passing through a sensitive galvanometer, if its needle i deflected it may be assumed that the points are at the electrical pressure.

An actual mechanical force is exerted on the substance rating two points at different electrical pressures, and thi increases as the difference of pressure increases. Whe difference of pressure gets large enough the substance is act cracked and an electrical spark passes which tends to eq the difference of pressure.

Electrical Pressures in Practice.—While the exact valu the same classes of work differ somewhat, the best values determined for each special case, the following general ideas be of value:

For ordinary electric bell work, from	2 to	4
" " annunciator " "	5 to	8
" telephone work, transmitter circuit, from	2 to	3
" electric lighting, alternate current systems in houses	52 to	104
" " " direct " "	110 to	220
" " " " " on vessels		80
" " motors, " "	110 to	220
" " railways	500 to	600
" " lighting, alternate current system, street mains	1100 to	2200
" " power transmission to distances of several miles	3000 to	20,000

's Law, which is the relation existing between ssure and resistance of a circuit, is the most important law electrical science, and an intelligent application of it will ve most problems which the ordinary engineer will meet. s law is as follows: In an electric circuit the total current pères] is equal to the total electric pressure [in volts] died by the total resistance [in ohms]. In shorter form it is ressed by the formula $C = \frac{E}{R}$, where $C =$ current in ampères, $=$ pressure in volts, and $R =$ resistance in ohms. Several exples will illustrate its use.

Example 1.—In a certain electrical circuit there is an electrotive force or electrical pressure of 4 volts. The total resiste of the circuit is 2 ohms. How much will be the current?

Ans.—$C = \frac{E}{R} = \frac{4}{2} = 2$ ampères.

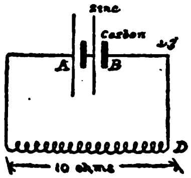
Example 2.—What electro-motive force or electrical pressure st be used to force a current of 10 ampères through a circuit ose resistance is 10 ohms?

Ans.—$C = \frac{E}{R}$ or $E = C\,R = 10 \times 10 = 100$ volts.

Example 3.—If under a pressure or electro-motive force of 100 ts we get a current flow of 20 ampères, what is the resistance of circuit?

Ans.—$C = \frac{E}{R}$ or $R = \frac{E}{C} = \frac{100}{20} = 5$ ohms.

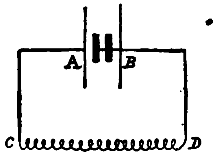
When there is more than one electro-motive force acting in a cirt, we must use for the value of E in the above formula the resultof all the separate electro-motive forces ing. When there are several resistances a circuit their sum must be used.



Example 4.—Suppose we have two batter- one giving 2 volts and the other 1 volt, ir plates being zinc and carbon, but *erent solutions being* used in each. Con- *the zinc of one to the* carbon of the other, and then connect to *A* a piece of wire having a resistance of say 10 ohms, as sho the sketch. When connected in this way—that is, in seri helping each other—the electro-motive forces are added, a total electro-motive force is 2 + 1, or 3 volts. The ba themselves have some resistance, and also the lead wires *A* *B D*. Suppose that the resistance of one battery is 4 ohms a other 2 ohms, the resistance of *A C* and *B D* each 1 ohm. the total resistance of the circuit is $10 + 1 + 2 + 4 + 1 = 18$

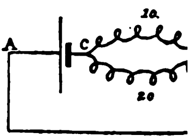
The current will be $\frac{\text{resultant } E}{\text{Total } R} = \frac{3}{18} = \frac{1}{6}$ ampères.

Example 5.—Suppose that one of the batteries was reve that the two zincs are connected together as in the sketch. T teries now oppose each other and the ant or effective electro-motive force is or 1 volt.



The resistance of the circuit is as 18 ohms, and the current will be $\frac{1}{18}$ a

Calculation of Current in Divide cuits.—Suppose that the battery has an electro-motive of 2 volts, that its resistance is $\frac{1}{3}$ ohm, that the resistance lead wire *A B* is 3 ohms, and that between *C* and *B* w two paths of resistance 10 and 20 ohms each. What will be the total current flowing through the battery and through *A B*? First find the total resistance of the circuit. The joint resistance between the points B and *E* is, as previously shown under "Resistance," equal to $\frac{10 \times 20}{10+20} = \frac{200}{30} = 6\frac{2}{3}$ The total resistance of the circuit is therefore $6\frac{2}{3} + \frac{1}{3} + 3$ ohms. The current is equal to $\frac{E}{R} = \frac{2}{10} = .2$ ampères.



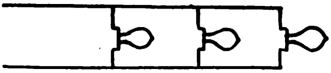
part of the current flows through each branch? Obviou *greater* part of the current will flow through the branch havi smaller resistance. $\frac{10}{30}$ or $\frac{1}{3}$ ampère will flow through the anch, and $\frac{20}{80}$ or $\frac{1}{4}$ ampère will flow through the other anch.

Practical Approximation.—If the resistance of batteries or nerator and the leads is small compared to that of the main sistance in circuit, we may neglect them, using for R in the rmula the resistance of the external circuit. This is generally e case in electric lighting circuits, where the resistance of the nerator will rarely exceed one-hundredth of an ohm, and where e resistance of the line wires will usually be less than one-ventieth of the joint resistance of the lamps.

Example.—On a 110 volt circuit what is the current [total] hen one sixteen-candle-power lamp of 220 ohms resistance is rned on? $E = 110$, R is practically 220 ohms. The current $= \frac{110}{220} = \frac{1}{2}$ ampère.

What is the current [total] when two lamps are turned on? he joint resistance of two similar lamps is $\frac{220 \times 220}{220 + 220} = \frac{20 \times 220}{2 + 220} = 110$ ohms, or *half* that of one lamp. The total current $= \frac{110}{110} = 1$ ampère. The current through each lamp is the me, and is $\frac{1}{2}$ ampère as before.

With three lamps turned on the joint resistance is one-third of 20, or $73\frac{1}{3}$, and the total current is $\frac{110}{73\frac{1}{3}} = 1\frac{1}{2}$ ampères, and e current through each lamp still $\frac{1}{2}$ ampère. Turning on ne lamp then adds $\frac{1}{2}$ ampère to the total current. The lamps re connected in multiple as shown in the figure.



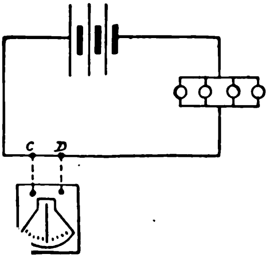
The use of alternating currents complicates the calculation of urrent, pressure, and resistance by Ohm's law, and the method f making such calculations is outside of the scope of this book, nasmuch as the ordinary engineer would rarely be called upon o do so.

CHAPTER XXX.

ELECTRICAL MEASUREMENT.

The four quantities which the engineer is likely to wa measure are current, electro-motive force, resistance, and p On direct current circuits the measurement of all these is si provided instruments of proper range are available. To d alternating current-measurements would carry us beyonc scope of this volume. The instruments needed are an ami and voltmeter of proper range. Every dynamo switch-boar an ammeter and voltmeter, which may be used for many o methods given if no other instruments are available. Most plants have also a portable voltmeter made by the Weston trical Instrument Company, reading from 0 to 150 volts. quently a second scale is added, reading from 0 to 5 or 0 volts, which is very useful. With the addition of a W portable ammeter reading from 0 to 15 or 0 to 25 ampère engineer is able to make most of the measurements necessar

These instruments consist of a permanent horseshoe m between the poles of which is a coil of wire swung on de jewelled pivots. The terminals of the coil lead to two bin posts. The instrument is a reversal of the galvanometer ously described, as in the galvanon the coil is fixed and the magnet piv while in the Weston instrument magnet is fixed and the coil is r ble.



Measurement of Current.—Su we have a circuit similar to that i sketch and we desire to measur current taken by four lamps. If are 16 candle-power (16 c. p.) l a 110-volt circuit, we know that they will take w ampère each. Therefore to measure accurately their current need an ammeter intended to measure small currents. To empt to measure it with the switch-board instrument designed currents of several hundred ampères would be like trying to igh a pound of flour accurately on a pair of hayscales. If we ve an instrument of proper range connect its terminals to two ints on the circuit as *C* and *D* by wires, as shown by dotted es. Then cut the circuit between *C* and *D*. The total current l now flow around through the ammeter, and the reading of needles will, if the instrument is correct, give the current in pères.

Notice that one terminal is marked + and the other —. If instrument is not connected properly, the needle will move or to move to the left of the scale. In this event reverse the wire nnections from the points *C* and *D* to the instrument. Such instrument tells the polarity of the circuit—that is, which is higher pressure and which the lower pressure side. When the binding-post is connected to the higher-pressure side of the cuit the needle deflects in the proper direction.

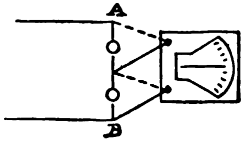
Method with Known Resistance.—If no ammeter of proper nge is available, we may perhaps have a resistance whose value know and which will carry the current to be measured witht much heating. In this case with the aid of the voltmeter we n measure current. Suppose we have a resistance which we ow is 1 ohm and a portable voltmeter with an additional scale ading from 0 to 15 volts, and we want to make the current-asurement just described. Put the resistance in between *C* and and connect the voltmeter terminals to the ends of the resistce. Suppose the reading of the voltmeter was 2.3 volts. The rrent through the resistance is by Ohm's law equal to the eleccal pressure or electro-motive force between its terminals dided by the resistance, or $\frac{2.3}{1}$, which is 2.3 ampères. This is the ethod used in the Weston switch-board instruments, a resistance known *value being placed* in the main circuit of the dynamo d *two leads taken off* from its terminals and run to a voltmeter, which instrument has, however, had its scale marked by trial with a standard ampèremeter, so that its deflections point to a number on the scale corresponding to the number of ampères flowing through the resistance. This known resistance is called the ammeter shunt. The instrument will not read ampères correctly with another shunt or other leads.

Measurement of Electro-motive Force.—With a voltmeter of proper range available it is only necessary to attach its terminals to the two points the difference of whose electrical pressure, or whose voltage, as we say, it is desired to measure.

When the voltage to be measured is greater than the range of the instrument there are two methods available:

1. Divide the voltage into two or more parts and measure the parts.
2. Increase the range of the instrument.

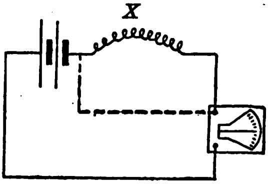
To use the first method, suppose we want to measure a voltage which we know is about 220 volts with a 150-volt instrument. Connect between the two points *A* and *B*, whose voltage is wanted, two 110-volt lamps in series. Then make the connections shown by the solid lines and read. Change the connections to the dotted positions and read again. The sum of the two readings will be the voltage between *A* and *B*. In the other method it is necessary to have a known resistance, to place it in series with the voltmeter, and also to know the resistance of the voltmeter. This last is usually given on the box containing the instrument. A resistance just equal to that of the instrument doubles its range. In general, to get the value of the reading of a voltmeter when a resistance has been put in series with it, multiply its reading by the sum of the resistance of the instrument the auxiliary resistance, and divide the product by the resist- the instrument.



urement of Resistance.—With an ammeter and voltmeter er range this measurement can be made by putting the

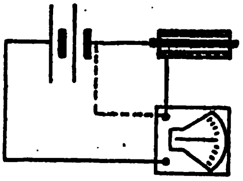
in series with the resistance and connecting the volt-
its terminals. Send a current through it from any con-
source and read both instruments. By Ohm's law
r $R = \frac{E}{C}$. Therefore the resistance equals the reading
ltmeter divided by that of the ammeter. The range of
eter must be suited to the current which the resistance
y without undue heating. This method is particularly
for measuring small resistances, such as armature re-
, samples of wire, bars, etc.

eter Method.—For measuring high resistances, the port-
meter and some current-generator are all that is needed.
hod requires two readings of the instrument. For the
ling the instrument is connected to the terminals of the
enerator. For the second reading the unknown resist-
put in series with the volt-
d then the two connected to
rator. In the figure X is the
resistance, and for the first
the connection shown by the
ne is made. For the second
he connection is as shown by
lines. To calculate the resistance from the readings divide
reading by the second, then multiply the quotient by the
e of the voltmeter, and from the product subtract the
e of the voltmeter. This method is applicable more
y to the measurement of high resistances of 1 meghom
although lower resistances can be so measured.

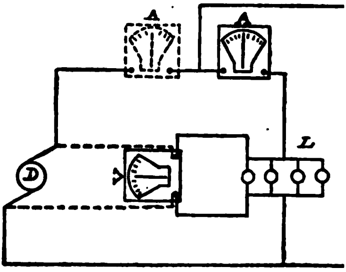


150 Weston voltmeter usually has a resistance of about
hms. By this method such an instrument would measure
000 to 400,000 ohms quite accurately—say, within 1 per
d from 4000 to 1,000,000 ohms fairly accurately—say to
per cent. For the measurement of the insulation resist-
iring *systems, cables*, armatures (from coil to frame), and
(*from conductor* to frame) this method is extensively

employed, special voltmeters having a resistance of 40, or over being desirable to give greater accuracy in meas above 1 megohm. As a rule, in such measurements accuracy is desired, it being merely necessary to ascert insulation resistance is greater than a certain amount— tures and field coils generally 1 meghom. In making the electro-motive force used should be about the san insulation will be subjected to in use. Frequently a hi tion is shown by a test made with small electro-mot where the application of the h ing electro-motive force res breakdown. The connectio made for testing an insulati ance are shown in the figure. black line represents the co the white space represents th ing medium, and the cross-hat tion represents the lead sheath of a cable that is being the frame of the dynamo if armature or field is being t a wiring system were the subject of test, the cross-hatch would represent a gas or waterpipe. The dotted line c would be made while taking the second reading.



Measurement of Power.—The power used in any c pressed in watts, the electrical unit of power, is equal to the product of the ampères flowing through the circuit and the voltage between the terminals of the circuit. The power in a circuit or in any *part of* a circuit can, *fore,* be measured with a voltmeter and ampère



e sketch consider first only the solid lines. *A* is an ammeter, d *V* a voltmeter. *D* represents a dynamo which is supplying o groups of lamps at *L* and *M*. Suppose, first, it is desired to ıow how much electric power is used by the group of lamps *L*. ıe ammeter and voltmeter are connected as shown by the solid ıes, and the ammeter thus measures the current flowing through e lamps, while the voltmeter measures the pressure between eir terminals. The product of the readings of the two instru- ınts will give the power in watts. Dividing this product by 6 will give the horse-power.

If the total power given out by the dynamo is desired, connect e instruments as shown by the dotted lines; the ammeter then ıasures the total current flowing through the main circuit and e voltmeter measures the electro-motive force between the dy- mo terminals.

Meters are instruments for recording either the ampère-hours watt-hours, the watt-hour being $\frac{1}{746}$ of a horse-power-hour. direct-current work there are two kinds in general use in this ıntry, the Edison ampère-hour-meter and the Thomson record- ; watt-meter.

The Edison meter is an electro-chemical meter; the current to measured, or rather a known fraction of it, one-thousandth, is l into a depositing-cell consisting of two zinc plates suspended a solution of zinc sulphate. The current takes zinc from one the zinc plates and deposits it on the other plate. The latter ıte is weighed at the beginning of each month, and from the in in weight and the known electro-chemical equivalent of zinc e number of ampère-hours is calculated.

The Thomson recording watt-meter is a small motor whose ld coils are connected into the main circuit, so that the total rrent runs through them. Its armature is connected across the ıins. The greater the main current, which is determined by e number of lamps turned on, the greater the force tending to rn the armature, and hence the faster will it turn. Its shaft is ınected to a revolution-counter similar to that used in a gas-meter, and its dials graduated by comparison with a standard so to read properly in watt-hours.

The advantage of the Thomson meter over the Edison is th the simple reading of dials gives the power-consumption, where the Edison meter is not direct reading, but requires careful weig ing on a delicate balance and after that an arithmetical calcul tion. The Edison meter, on the other hand, requires much le power to operate it, which is of importance for central-statio work. For isolated plants, of course, the Thomson is much to b preferred.

Recording Voltmeters and Ammeters.—Instruments simil in appearance to recording thermometers are available, in whic the needle makes a continuous record on a revolving paper di similar to that of a recording pressure-gauge. Electrically the are galvanometers with a fixed coil and a movable magnet whic carries the recording needle.

CHAPTER XXXI.

ELECTRIC GENERATORS.

Batteries or chemical generators are used where the work t be done is so small that it can be done more cheaply by them tha with dynamos, and also in some cases where the introduction o an engine necessary to drive the dynamo would be objectionabl if not altogether out of the question. Their greatest use is i operating bells, annunciators, burglar-alarms, time-clocks, tele graphs, telephones, etc.; but many are used by physicians fo tery and for surgical lamps, and by dentists and m ics for driving small motors, operating fans, grinders, dent etc.

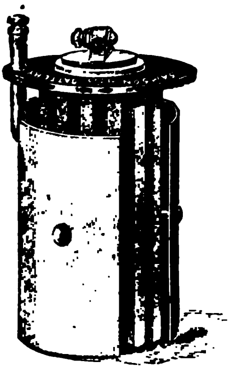
ry or storage batteries are those which, after havin uch a time that their active materials are een changed into chemical substan t do not act on each other, can, by having an electric current sed through them in the opposite direction from some other erator, be brought back into their original condition by having ir chemical actions reversed.

'rimary batteries are those cells which are not reversible, and, refore, whose active materials must be renewed from time to e. Many batteries which are in this respect used like primary teries can be reversed; as, for example, the Daniell cell. The : and solution of this cell are, as ordinarily used, renewed. n necessary; but the cell is reversible and can be used as a ·age cell.

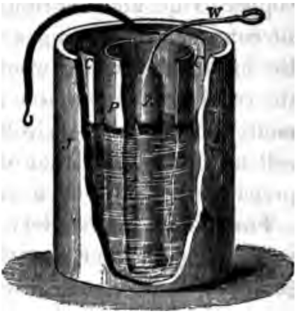
The two classes into which primary batteries are usually died are closed-circuit batteries and open-circuit batteries.

In open-circuit cell or battery is one which from its nature is y fitted for use on circuits which are for most of the time open, ıg closed only at the moment when work is to be done, and n the nature of the work remaining closed only a few moments a time. Such circuits are those for bells, annunciators, rms, gas-lighting, and telephones. For such circuits the types ing zinc for one plate, carbon for the other, and the two imsed in a single fluid, serve admirably, and the combination erally used is zinc and carbon in a solution of sal-ammoniac. s gives an electro-motive force of 1.5 volts nearly, and a fairly resistance, the ordinary sizes and styles having from $\frac{1}{10}$ to $\frac{5}{10}$ ı. If the circuit of the cell is kept closed for any length of time, electro-motive force drops and the resistance rises, owing to collection of hydrogen-particles on the carbon plate. If the uit is opened, these disappear in a short time and the cell reers its original strength. In the class of work mentioned ve this is just what happens. If there were some means of get- rid of these hydrogen-particles as fast as they were produced, cell would be very much improved and would become availe for a greater variety of work.

ı ***very porous carbon*** takes up in its pores particles of oxygen *:h are held in solution* in the water. These oxygen-particles unite with more or less of the hurtful hydrogen-particles and form water, so that the bad effect, which is called polarization, is much diminished. A French inventor, Leclanché, devised a much better means of doing this by putting in cakes of manganese binoxide, a strong oxidizing agent. This gives up a part of its oxygen, which attacks the hydrogen-particles, forming water. This type of cell is now known as the Leclanché prism-pattern. Very excellent cells are made by making the carbon in the form of a thin, hollow cylinder and putting inside the porous cylinder powdered manganese binoxide. When it is desired to reduce the internal resistance of a cell to the utmost the zinc, instead of having the usual pencil-form, is made into a hollow cylinder outside of and very close to the carbon cylinder. The means of diminishing battery resistance are to increase the surface of the plates and to diminish the distance between them, so that two hollow cylindrical plates meet the conditions very satisfactorily. The carbon cylinder battery with pencil zincs is entirely satisfactory for bell work, etc., in small houses; but where signals are made with great frequency and sometimes for two or three minutes at a time, as in hotel annunciators, elevators, telephones, and similar work, the Leclanché pattern should be used, and in the most severe service it will be advisable to use the pattern having cylindrical zincs.

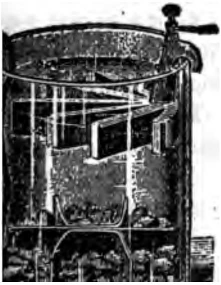


Closed-circuit cells must be capable of operating on closed circuits continuously without an appreciable lowering of electro-motive force or raising of resistance. The cells chiefly used for such work are the Daniell cell and the Edison-Lalande. In the Daniell the harmful hydrogen which would lower the electro-motive force and raise the resistance is gotten rid of by a second solution, which is a strong oxidizing and which burns away the hydrogen. In the Lalande cell hydrogen set free is attacked by copper oxide, which re- lts in forming water and metallic pper.



Daniell Cell.—The original form this cell is illustrated in the cut, iere *C* is a copper plate dipping o a solution of copper sulphate strong oxidizing agent), *Z* is a ic plate dipping into sulphuric id, and *P* is a porous cup which ntains the sulphuric acid. The id will penetrate into the pores the cup and will come into con- t with the copper sulphate, but is prevented by the cup from xing with it to any great extent. The action is as follows: nc dissolves in the acid when the circuit is closed from zinc to pper, setting free hydrogen at the outer surface of the porous p. The copper sulphate attacks this hydrogen, forming water d depositing copper on the copper plate.

The gravity pattern is shown in the cut. The two liquids ving quite different specific gravities will not mix to any great extent if the jars are kept quiet. This is especially the case when the circuit is closed and a current is flowing. On open circuit mixture takes place, and the rising copper sulphate coming in contact with the zinc plate, zinc is uselessly dissolved. On this account the Daniell cell is not suited for open-circuit work. The electro-motive force of the Daniell is about 1 volt, and the resistance of ordinary size cell about 4 ohms.

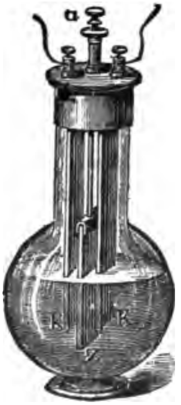


Gravity Cell.

The Edison-Lalande cell consists of a ite of zinc *and a plate of* black oxide of copper (held in a cop- *frame) suspended in* a solution of caustic potash. On closed circuit the zinc dissolves, forming potassium zincate, and gen is set free. This is at once attacked by the oxyge copper oxide, and the result is the formation of water an lic copper. By putting a film of oil on the top of the the local action which would otherwise take place is obvi the cell becomes available for open-circuit work. As its motive force is only $\frac{8}{10}$ volt and its resistance for the sa cell no lower than that of the Leclanché pattern, the preferable for most open-circuit work, as it requires less c

For motors and cautery work cells are required to give current for a longer time than the zinc-carbon sal-ammon could do, and for such service a different class of cells is er whose characteristics lie somewhere between those of tl circuit and the closed-circuit cells. The most commonly the bichromate cell.

The bichromate cell has zinc and carbon plates in a of chromic acid, made by mixing potassium bichroma sulphuric acid. It gives an electro-motive force of over and it has a low internal resistance. One great disadvar this cell is that even when the circuit i the zinc plate is rapidly consumed. T this trouble one form has an arranger holding the zinc plate up out of th when not in use, while in another fori ous cup is used containing the zinc wi dilute sulphuric acid. The use of t while preserving the zinc, increases sistance of the cell.



hromate Cell.

Care of Cells.—It is important tha materials of a cell should be pure. zincs and chemicals contain impuritie greatly increase wasteful local action, b the zinc is eaten up while no current duced.

lgamation is a process of alloying the surface of i ercury, which protects the zinc from much of this wasteful ction. Zincs are usually more or less amalgamated when purhased, but the process of amalgamation is very easy. The zinc dipped into dilute sulphuric acid to clean it, and then with a loth mercury is rubbed on the surface till it presents a uniformly right appearance.

Renewal of zinc plates should take place when they are nearly ten away. The remnants can be sold or remelted if there is at and a suitable mould.

A carbon plate needs no change till its pores are filled, so at hydrogen can no longer be taken up. It will, of course, still ntinue to work, but not so satisfactorily. It may be improved y boiling it some hours in water, but after one or two such boilgs, if the operation of the cell is not satisfactory, a new carbon ould be put in.

Where the Leclanché disk or hollow cylinder type is used the arbon is satisfactory till the manganese has given up all the oxyen that it will. After this a new carbon should be put in. It not possible by the eye to tell whether the oxygen is exhausted xcept by the appearance of a greater number of hydrogen bubles than usual on the carbon. A voltmeter attached to the cell hen the circuit is closed will show, by the too rapid drop of lectro-motive force, that the carbon or solution needs attention.

In the Edison-Lalande cell the two plates and solutions need hange all at once, and the proper time to attend to this can be old by the condition of the zinc plate. When nearly gone it is ime to put in new materials.

Solutions.—In the sal-ammoniac cells of ordinary size put a uarter of a pound of sal-ammoniac and add *warm* water. The dition of cold water is liable to crack the jar, as sal-ammoniac dissolving produces a considerable degree of cold. The soluon is clear and colorless. If it becomes milky, it shows that ore sal-ammoniac is needed. In the ordinary use of a cell ater gradually evaporates and the cell should be occasionally *filled.*

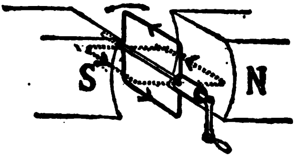
In the Daniell cell, gravity pattern, enough copper-sulphate crystals are put around the copper plate to cover it. Water is put in so as to cover the zinc about one-half inch. A little sulphuric acid is added. After a few hours on closed circuit zinc sulphate will be formed, and a fairly sharp line of demarcation will be seen separating the blue solution of copper sulphate from the clear solution of zinc sulphate. As the cell continues working this line will go lower and lower; when it goes past the half-way distance dip out or siphon out some of the zinc sulphate and replace it by clear water poured in through a funnel reaching down into the solution. If the zinc sulphate gets too strong, it will crystallize on the walls of the jar; while if the copper sulphate is too strong and its level rises up to the zinc, local action will take place and the zinc be wasted.

Bichromate Solution.—To 2 pounds of strong sulphuric acid add, stirring constantly, 1 pound of bichromate of potash, powdered, and then after a few minutes add slowly 12 pounds of water. The mixture will become quite warm. After the cell has been used considerably, if the color of the solution becomes bluish, add more potash. If the voltage falls off, but the orange color remains, more sulphuric acid is needed.

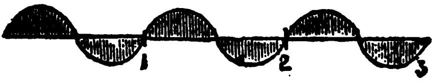
Dry cells, so called, are cells in which the solution has been reduced to a pasty condition by adding some substance to the fluid. The only advantages of such cells are their portability. Their resistance is much higher and they polarize much more readily than the ordinary forms.

Various types of cells will be found described in full in Prof. H. S. Carkart's *Primary Batteries* and the work on *Batteries* by Mr. Park Benjamin.

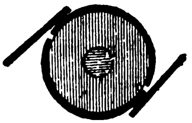
The dynamo may be regarded as a sort of electrical pump continuously pumping electricity from a low pressure to a high pressure. The energy necessary to do this is generally derived from a steam engine, but, of course, may be obtained from any source of power. For electric lighting or power in isolated plants dynamos or generators are designed so that when run at co ıt speed they automatically maintain a practically constant erence of electrical pressure whatever load may be thrown on m, up to the limit of their capacity. As electric power is al to the product of current by pressure—that is, ampères by ts; and as the volts are practically constant, the power will be portional to the ampères flowing—that is, to the number of ıts thrown on. If the lights burning are few, the ampères l be few and the demand for power on the engine correspondly small. With more lights more ampères are required, hence re power from the engine, and the cut-off will be lengthened the governor.



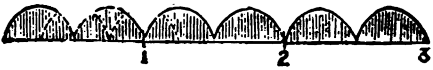
he ideal simple dynamo consists of a single coil of wire rotat- between the poles of a magnet, n the figure. Starting with the in the vertical position, and ning it right-handed, as shown the arrow, we find, by applying Fleming rule described above, t the current will flow in the coil the direction shown by the arrow-heads until it has gone half- y around. During the next half revolution the rule will show t the induced currents flow in the opposite direction. There hen a reversal of current twice each revolution. If we meas- the strength of the current at different parts of the revolu- ı, and graphically show the variation by a curve, in which izontal distances from the starting-point represent the angle ned through and vertical distances represent current-strength that angular position, we shall get a curve such as is shown in the



ıre, which *represents three* complete revolutions. The current *ts at zero, and increases till* one-quarter turn has been passed through, and then diminishes, till at the half-turn it is zer From there the *direction* of the current reverses, as shown curve, going below the horizontal line, and it increases to th quarter point, and then diminishes to zero again. Such rent is called an alternating current, and such a dynam ideally simple alternating current dynamo. The above represents also the variation of electrical pressure of dynamo. If it were desired to make a dynamo to give a pressure, we could do it in one of three ways: by increas speed of rotation, by increasing the number of turns in or by increasing the strength of the magnet. While fluctuating or alternating current could be used for light for small-power work we have no satisfactory large mot able of being run by it, nor can storage batteries be charg it. It is therefore necessary to introduce some device wh rectify the current—that is, make it flow always in th direction in the circuit outside of the dynamo, although nates in the coil. Such an arrangement is called th mutator.

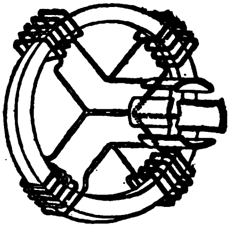


The commutator is a purely mechanical device, and as shown in the figure, of a split ring, to one side of which of the coil is permanently fastened, the other side the other end of the co ends of the external circuit are conn brushes which rest on these, one brus ing one commutator segment and the brush the other segment. Just as gets into the vertical position where current reverses, eac changes from the segment with which it was in contact other, so that the effect of the reversal of current is neutr

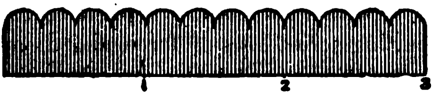


as the external circuit is concerned, the curve of such cur- its now being as shown in the sketch. In practice the commu- or segments are insulated from each other and from the shaft sheet mica.

The armature, as the moving part is called, is in actual chines made up by winding the conductor on an iron core. e object of the *iron* core is to keep as many as possible of the gnetic lines produced by the magnet in the space where the iductor is moving. Without the core a large part of them uld stray out of this space and would not be cut by the coil, l the electro-motive force produced would be very much smaller .n when an iron core is used. This core is made in two forms, ich give rise to two different classes of natures, each possessing certain advan- es, called the *Gramme ring* and the *m-wound* armatures.

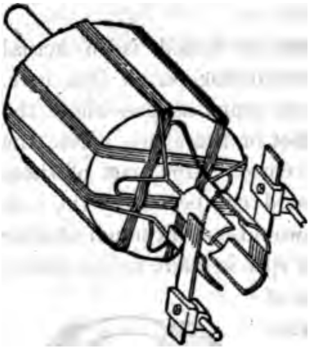


Ring Armatures.—The figure illus- tes a ring armature with four coils in- ad of one, as in the ideal dynamo, and o shows what changes are necessary in commutator. It will be seen that re are as many parts or *segments*, as they are called, in the nmutator as there are coils or *sections* in the armature. The ve of the currents shows the advantage of the greater number sections in the armature, the fluctuations in the strength of cur- it being very much less than with one coil. In practice from to 120 segments are in general use.

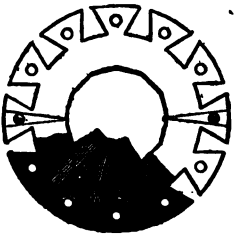


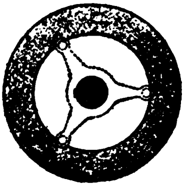
Drum-wound armatures have an iron core of cylindrical shape, winding for a four-coil armature being clear from an inspec- *n of the figure.* Although it possesses some important advan-

tages over the ring armature, it is less easy to wind and fau it are less easy to locate and remedy.



Armature cores are always nated—that is, of thin ci disks of soft iron or mild These disks are of a shape what as shown, being slotted to make a groove in which th can be laid. Formerly the were laid on the surface an small iron binding wires wound around the periph hold the armature conduct place against the action o trifugal force and also the netic pull which exists between the field magnets an currents in the armature wires. By making use of g the sides of the slot take the strain or pull due to magn thus making the armature much stronger mechanicall still further advantage is that the clearance between the ro armature and the pole pieces of the field magnet can b much reduced. The reason of laminating the armatur prevent the production of excessive currents in the iron cor for a moment we consider the core as made up of a num rods parallel to the armature shaft, it is plain that we hav of conductors cutting across lines of force, and an applicati Fleming's rule would show that the direction of the cu would be parallel to the staff. If we laminate these crosswis insulate the laminations, we shall enormously increase the ance to these useless currents, and since we have by lamin done nothing to change the electro-motive force producing they will be diminished to a very small amount. The insul is done by enamelling the disks or by separating them pieces of thin varnished paper. The figure shows a slotted gramme winding. The core disks are usually held o strong heads with bolts running from one head through in the disks to the other head, the bolts being insulated the disks. The disks are connected to the shafts through s keyed to shaft as shown. This construction leaves the of the armature hollow, so that air can enter and pass out





e purpose of dissipating the large amount of heat produced armature coils and core.

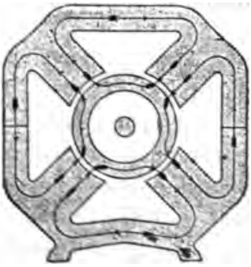
ɜ **armature conductors** are of copper wire insulated with ıyers of cotton, and are further insulated from the core by ɔr other insulating materials, of which mica is the best. In ,rge-size machines copper bars of rectangular section are connected at the ends by specially shaped pieces of copper. ize of the conductors is made such that, with the ventilation ıed by the air circulating through them, they do not reach a ꞉rature more than 80° to 85° F. above that of the surround- r after a run of six or eight hours at full load.

looking at the typical four-coiled armature it will be seen here are two paths for the current from one brush through the ,ure coils to the other brush, and as these are of equal resist- one-half of the total current flows through each branch. If, ore, as sometimes happens, one coil is broken, there is still uit closed from one brush to the other, and we cannot with ;netic testing-bell find out that there is a break. In such a the output of the machine would be very much less, and would be serious sparking at the commutator.

The field of a dynamo is the magnet whose office is to magnetic lines of force for the armature coils to cut. T magnets used were permanent magnets; but it was soo that magnets made by carrying current through wir around an iron core were for a given size and weig stronger, so that now about the only case in which pe magnets are used is the small magneto-generators used in tion with telephone instruments. According to the nur poles in the field dynamos are classed as bipolar or multi

A bipolar machine is one having but two poles in its fi net, the arrangement being similar to that of the idea dynamo.

A multipolar machine is one having more than two p will always have an even number, such as four, six, eig depending on the size of the machine, half of the pole north and the other half sout The cut shows a typical four-p chine, and the arrow-heads g direction of the lines of force, it will be noticed, are closed lo turning to their starting-point.

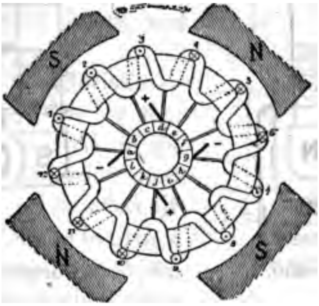


The advantages of a mu generator over the bipolar are a given size and speed of rot higher output can be obtained, all modern generators of any size are made multipolar.

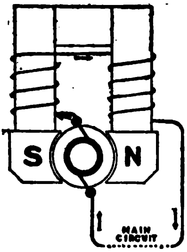
The winding of the multipolar machine armature is sh the cut, which represents a four-pole machine with ring ar The two positive brushes may be connected to each other two negative brushes to each other by wires, so that it is n lutely necessary to have as many brushes as there are pol this has not been found desirable in practice, and nearly chines have the same number of brushes as poles.

A classification of dynamos is further made accord ing around the field and the manner in which it

to the circuit. With a certain armature turning at a cer-
ed, the dynamo designer must provide a winding capable
ucing a certain number of lines of force, from pole to



order that the machine shall give the electrical pressure
. This winding may be a comparatively few turns carry-
arge current or many turns carrying
current, the number of lines being pro-
al to the product of *ampères* times turns,
product is called the *ampère-turns*.



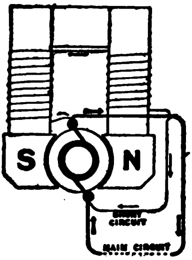
eries-wound machine is one whose
wound with a few turns of wire
which flows the entire current given
the machine.

shunt dynamo is one in which only a
raction of the total current, perhaps
ntieth, flows around the field coils. The number of turns
oils is, however, very great.

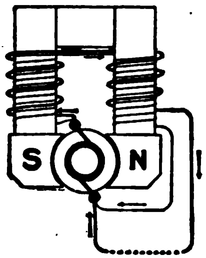
compound dynamo is one which has both the coarse-wire
of the series machine and the fine-wire winding of the
nachine.

advantages of the three types are best shown by means
rve, called the *characteristic curve*, or, more briefly, the
ristic, which bears to the dynamo somewhat the same re-

lation as does the indicator-card to the engine. It is obtaine taking measurement *at constant speed* of the voltages of the chine and the corresponding ampères, at different loads, fro

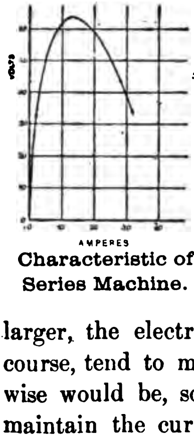


Shunt Dynamo.



Compound Machine.

load to full load, and plotting these values as follows: Dist measured vertically from a horizontal axis represent volts horizontal distances represent ampères. curve drawn through the plotted p shows the behavior of the machine.

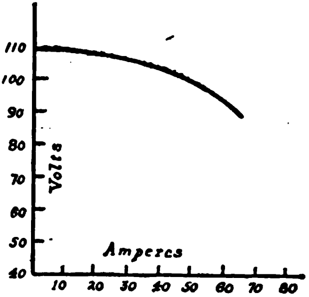


Characteristic of Series Machine.

Series Characteristic.—That part o curve to the right of the maximum poi the range over which series machine usually employed. It shows that as th rent increases the electro-motive force That is, on a circuit supplied by such a chine, if we should diminish the resis which would tend to make the cu larger, the electro-motive force will drop. This drop wi course, tend to make the increase of current less than it wise would be, so that such a machine automatically ten maintain the current in its circuit at a constant strengt series-machine is, therefore, used in constant current distrib as for arc lamps on long-distance circuits.

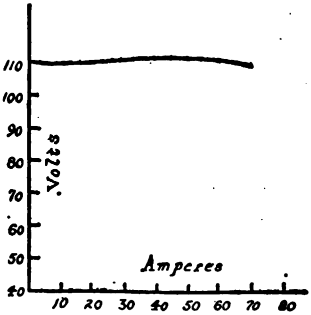
***Shunt* Characteristic.**—With the ammeter in the main ternal circuit the curve is a gradually drooping one.

essure is, however, fairly constant for all strengths of current, d the shunt machine would be ed where a constant pressure stem distribution is employed, for incandescent lamps and otors.



Characteristic of Shunt Dynamo.

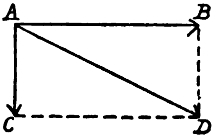
Compound Characteristic.—y carrying the main current ound the fields as well as the unt coils we get the joint effect two windings. The effect of e shunt coils alone is to give a arly constant pressure, as shown the characteristic above, but droops somewhat. The effect of current around the series coils to add lines of force, and the eater the current strength the eater number of lines is added, d consequently the higher the essure furnished by the machine. he series coils will, then, acting y themselves produce a rising aracteristic, as in the left-hand rt of the curve of the series aracteristic. (The right-hand rt is taken when the current s become so large as to saturate e magnet cores, so that adding rrent no longer adds lines of rce), while the shunt coil gives a falling characteristic. Therere by properly proportioning the number of series turns they can made to neutralize the drop of the shunt characteristic, and e machine then gives a practically constant pressure at all ads.)



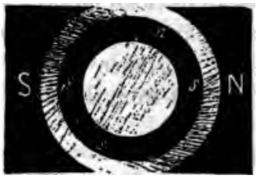
Characteristic of Compound Dynamo.

An over-compounded machine is one in which the series coil is given more turns than will just balance the drop of the s shunt machine. The characteristic will therefore rise, the increasing as we increase the ampères. When the voltage load is 5 per cent. more than at no load the machine is s be over-compounded 5 per cent. If the rise is 10 per cent said to be over-compounded 10 per cent. Most machin made over-compounded 10 per cent. to 12 per cent.; arranged that an adjustable shunt is placed across the ter of the series coil, by means of which the proportion of the current flowing through the series coil can be varied. B means the amount of over-compounding is easily adjusted. most isolated plants an over-compounding of 3 per cent. to cent. is used, 2 per cent. of which is useful in counteracti drop of speed in the engine at full load and the remain make up for drop of pressure in the wiring.

Armature Reaction.—The armature, consisting of an iro covered with coils of wire carrying an electric current, course, an electro-magnet. The poles are at the points o the brushes; that is, a line drawn from one pole to the would be parallel to a line joining the brushes. In the simple dynamo the poles would be vertical, as the line ing the two brushes is vertical. But the line joinin brushes is at right angles to the lines of force of the which in this case are horizontal. Therefore it is eviden the armature-poles are at right angles to the field-poles, an lines of force due to the magnetism are at right angles t lines of force due to the field alone. resultant direction of the magnetic fie lie somewhere between the directio the two fields due to magnet and arm and may be found by applying th allelogram of forces as in Chapter I. *A B* represent in direction and int the number of lines of force due to the field magnets, and represent likewise the lines due to the armature. Then A

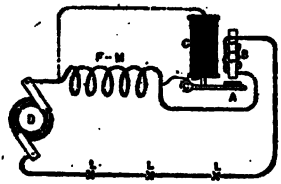


the direction of the resultant field. The cut shows this of the field in an actual arm- experiment being made with gs. When no current flows he armature coils the lines of horizontal, but when current ugh it the resultant field is ward in the direction of rota- e armature, as shown in the cut. The greater the arm- ent the greater the shifting of field. Now since the line ishes is at right angles to the resultant field, the brushes hifted forward, in order to prevent sparking when the e machine increases. The amount by which they are called the *lead.*

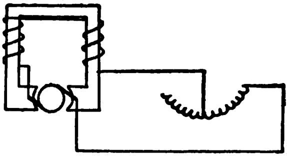


ad in small machines of older types is considerable, to 10 to 20 degrees. To diminish it we must make tic field due to the field magnets very strong relatively the armature. In modern machines this is done, with that after the brushes are properly set they need no to prevent sparking even when load is changed from ll load.

ion of Series Dynamos.—As previously stated, series are used almost exclusively on circuits whose current is desired to maintain constant whatever the number thrown on. Since the lamps are in series, the more ed on the higher the resistance of the circuit and the electro-motive force needed to keep the current at the lue. Although by using the machine on that part of cteristic to the right of the maximum, as explained *es characteristic,* the machine tends to regulate the press- atically, yet it is necessary to use special devices to satisfactory regulation. There are several ways in electro-motive force furnished by a machine may be ne is to shift the rocker arm carrying the brushes; but *severe sparking,* and if used in some arc machines requires a special construction of the commutator. A is to have an adjustable resistance in multiple with th and arrange this resistance so that when lamps are the resistance of this shunt path is lessened, thus ta current from the field coils and cutting down the ele force of the machine. The f the principle of the Brusl *D* is the dynamo armatur field coils, and *L*, *L*, *L*, the is a resistance made of ca connected in multiple witl coils, as shown. If lamps off, thus diminishing the re the circuit, the coil *C* raises its armature *A*, putting a the carbon disks. This diminishes the resistance of th cuit through *C*, and takes away more of the current fr coils, thus diminishing the number of magnetic lines o duced, and hence also the electro-motive force of the m lights are thrown on, the reverse action takes place.



The regulation of shunt or compound machines varying the current around the field coils; but as sucl give very nearly perfect regulation automatically so lo is maintained constant, only a hand-regulator, called is provided. This rheos of a number of coils o embedded in an insulat or mounted on porcelain contained in an iron fra box. An arm sweeps terminal points connect ends of these coils, as shown in the sketch. Moving to the left would cut down the electro-motive foı machine, and to the right would raise it. This re rarely used except when the speed changes or when is being started up.



roubles and Care of Dynamos.—In a book by Messrs. ;ker and Wheeler this subject will be found very fully treated. . Thompson's *Dynamo-Electric Machinery*, which is of the very test value in studying dynamos in detail, also has much of e as well. When a dynamo is in good order the only things iring attention more than in any piece of machinery are the mutator and brushes. The commutator should be cleaned or three times daily by holding on it while it is turning a cot- cloth. Afterward put a *very* little vaseline on the cloth. Oc- onally hold fine sand-paper against the commutator to smooth urface. *Never* use emery or oil on it. If it gets untrue— is, out of a perfect cylindrical shape after some months' use rough bad sparking—it must be turned down smooth by the of a lathe-tool rest and tool.

he brushes, which are now generally made of carbon or fibre- hite, must be carefully fitted to touch closely the commu- r-surface and the rocker-arm carrying them adjusted till there sparking at any load. Sometimes considerable labor must pent in securing freedom from sparking. After once adjusted erly they will run for weeks without any further adjustment. y should be carefully watched, however, and if they show any e of sparking they should be adjusted again till this disap- s.

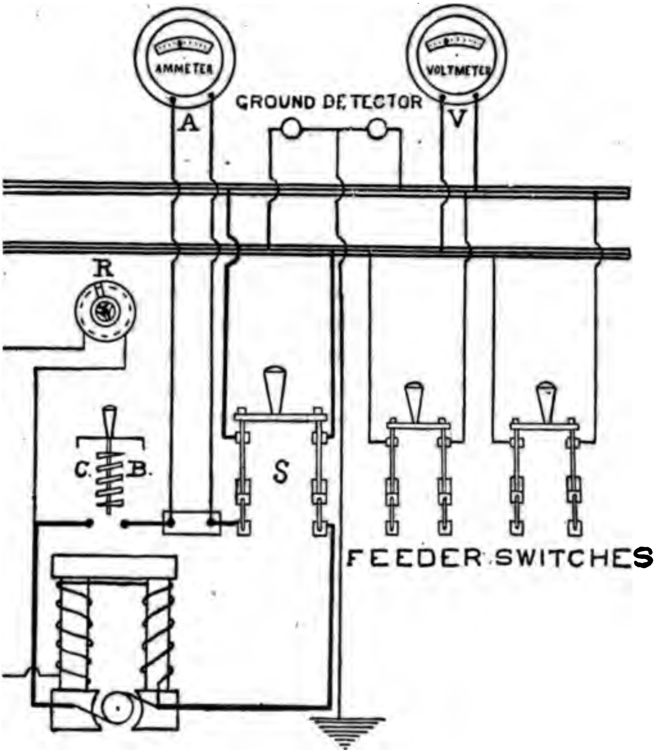
ttend to the commutator and brushes, keep everything clean dry, and allow no oil except in the bearings, and a dynamo in general give no more trouble than any piece of moving hinery.

CHAPTER XXXII.

DISTRIBUTION OF ELECTRICAL ENERGY.

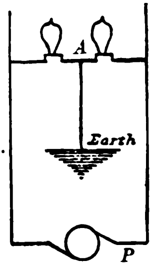
he production and distribution of electrical energy are very h like a small water-system, where water is pumped from a *to a high reservoir*, taken from the reservoir through pipes to the place where it is to be used, and *after use* led back to tank to be again pumped up and again used. The generato dynamo, driven by a steam engine, gas engine, or water-wh corresponds to the pump. The distributing-pipes in the wa system are replaced by copper wires for the electrical sys The high-pressure reservoir and low-pressure tank are repl by the switch-board bus bars, one of which is a high-pressure the other a low-pressure bar. The high-pressure bar is also ca the positive or plus (+) bar, and the other the negative or m (—) bar. They are each copper bars mounted on the marbl slate of which the switch-board is made, and are called *bus* or omnibus bars from the fact that all the current is carried them. The valves of the water-system are replaced by switc the water-meters by ammeters, and pressure-gauges by voltme Some devices which are used in electrical distribution have noth similar to them in water-systems, but the general similarit of great assistance in understanding electrical distribution.

The switch-board consists of one or more slabs of marble slate supported on a wrought-iron framework, on which mounted the bus bars, switches, meters, and other devices ne sary for conveniently controlling the system. Slate is used m largely, being inferior to marble only in appearance. It is so what cheaper and much more easily worked, being softer and l brittle. It can be finished by enamelling to resemble closely da colored marbles. The iron framework is usually made of ang irons and T-irons strong enough and stiff enough to support t weight of the marble and instruments. It should be set out fr a wall two to three feet, so as to give easy access to the back, which the bus bars and connecting straps are placed and wh the connections are made between circuit wires and switches. the series system of distribution which is described further on little used except for distribution to arc lamps for out-door wo and as this service is usually performed by central stations, will confine ourselves to the description of switch-boards for pa bution. The accompanying figure shows the arr when one dynamo is used to supply current and when two its run to the lamps or motors being operated. The switch onnected so that when in its present position the brushes of lynamo are connected each to one of the bus bars. If the le of the switch is drawn outward, the circuit between brushes bus bars is interrupted in both lead wires and the dynamo ture is no longer in connection with the bus bars. All lights d, *of course, be put* out and all motors would stop. The neg- *lead before it reaches* the switch passes through the ammeter



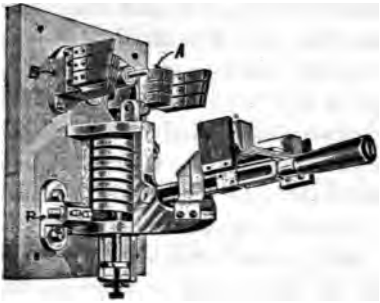
shunt *D*, so that whatever current the machine furnishes i ured by the ammeter *A*. Both leads pass through fus whose purpose is to protect the machine from being inju an accidental overload. They are made of an alloy of le tin, and of such size that they will melt when carrying a slightly larger (about 25 per cent.) than that for which t chine was designed. When they have melted, of cou machine is cut off from connection with the switch-board a cuits. These fuses do not, of course, protect the machin troubles within itself, but only from being overheated by a resistance of the circuit due to any cause whatever. O the uncertain action of large fuses, those designed to bl at 500 ampères and melting at perhaps 400° or 600°, tl generally giving way to magnetic circuit-breaking devices circuit-breakers, which will be described further on. *R* rheostat for varying the voltage of the machine, and voltmeter which measures, when connected as shown, the or difference of pressure between the bus bars. The two s at the right are to make and break connection between th ing circuits and the bus bars.

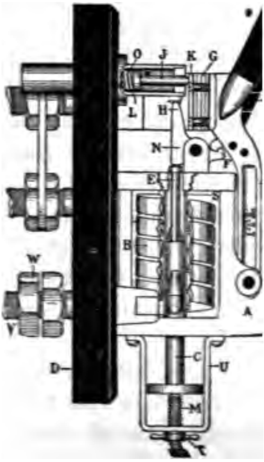
The two lamps connected in series between the bus bars showing if any part of the circuit becomes connected to e to any conductor connected with earth, such as gas-, wat steam-pipes, the steel frame of the buildi It is called the ground-detector.



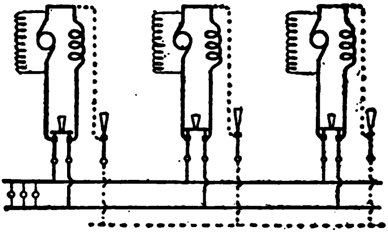
The ground detector consists of tw volt lamps connected in series with eac and across or between the bus bars junction between the two lamps is co to earth—*i. e.*, to a convenient water-pi long as the insulation of the circuit is a the two lights burn alike equally dim, si are designed for 110 volts at their te and they have only 55 volts under the uppose any point on the circuit, as P, is accidentally connected to earth. Then the left-hand light will burn bright while the right-hand one will burn exceedingly dim, or perhaps not at all. The reason is that the grounding of the point has put it in electrical connection with the point of junction of the two lamps, through a very low resistance. The current through the right-hand lamp is, therefore, diminished, its terminals being short-circuited. The left-hand lamp will have practically 110 volts between its terminals, since the joint resistance of the right-hand lamp and the other path from *A* to *P* is exceedingly small, and hence the pressure used up being also exceedingly small. If the point *P* were on the other side of the circuit, the right-hand lamp would burn brightly and the left-hand one very dimly. To find the location of the ground the switches are opened one by one till that one is found which, on being opened, relieves the ground. This circuit is then examined in detail with a magneto bell. The brightness with which one of the lights burns gives an approximate idea of how bad the ground is; but only very roughly. When real accuracy is desired a ground-detector is used consisting of a voltmeter whose zero-point is in the middle. It is connected so that one of its terminals is put to earth; the other by pressing one key is connected to the positive bus bar. The deflection of the neddle then gives the leakage current flowing through the insulation of the negative side of the circuit. Releasing this key and pressing another key connects the voltmeter terminal to the other bus bar and gives the leakage current on the other side of the circuit.

Circuit-breakers are switches so arranged that they are opened automatically when the current flowing through is too great for the circuit which they are designed to protect. When their handle on being opened breaks the positive and negative sides of the circuit it is called a double-pole circuit-breaker; when only one side is interrupted it is called a single-pole circuit-breaker. The movement of the handle is due to the action of a spring tending to push the handle outward, thus breaking the circuit. When everything is all right on the circuit, the handle being pushed in so as to close the circuit, it is held in, in spite of the spring, trigger. If the current gets too great, a coil of wire in of a helix, through which the current passes, draws up iron plunger, which hits the trigger and sets the handle opened by the spr two cuts show t of a common breaker of the s type. In the which shows th open, the current at the back of t ment at *P*, an around the coi terminal *A*. Th handle is closed rent flows across to *B* and out to the circuit. The seco shows the instrument in greater detail. *H* is the trigg holds the handle closed, and *O* is the spring which will open it if the trigger is unlocked. *C* is the iron plunger which is raised up to hit the trigger whenever the current through the coil *B* is too great. By turning the screw *M* in so as to raise *C*, the breaker will open at a smaller current. By turning *M* out, it will take a larger current to set it off.





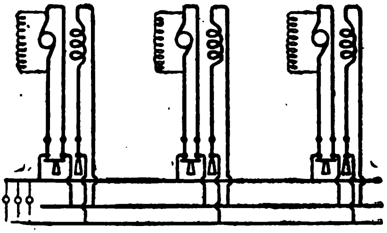
enerators in Multiple.— xtremely convenient lant has two or rators to be able n them in multiple on the same set of bus bars, for by this ngement when the load is light one machine will take care of it, as it increases additional machines can be started up and coned in to the bus bars to take care of the increasing demand. shunt machines may be run in multiple without any trouble, ing only necessary to get the second machine at the same voltas the first by means of the rheostat in the field circuit, and the machine switch can be thrown *in*, thus connecting the nd machine to the bus bars. When the machines are comnd, however, they do not work well together without some itional devices. Supposing that they have been thrown in tiple and each is taking its share of the load as shown by the neters. If the speed of one machine diminishes owing to belt page or any other cause, its electro-motive force will be less the reading of its ammeter will diminish. The reading of the neter of the other machine will increase, more current flowing ugh it. Therefore its series coils will produce more lines of e, thus raising its electro-motive force and making it take still e of the load. This will continue till the higher pressure hine is taking all the load and the current through the other hine drops to zero and reverses in direction, after which it be driven as a motor by the other machine. Some device t be used so that if one machine increases in speed relatively he other one, the increased current flowing will be sent und the series field-coils of the lower speed machine. The mpanying figure shows the arrangement, called the *equalizing ection*, commonly used. The equalizer connection, as here wn by the dotted lines, was first suggested by Gramme for es machines and by Mordey for compound. If made sufntly heavy, it will not only effectually prevent the reversal of rity of any of the machines so connected, but will, in a great sure, equalize the work done by the generators under varying litions of speed. Any number of dynamos may be connected in this manner, *and*, even if they are of different capacities, *machine will give* current in proportion to its rated output, provided the combined resistances of the leads to the bu the armatures, and the series fields, are inversely proporti the ampère capacities of the machines. Without the eq connections, or if these are not sufficiently heavy, a cha speed or of load is liable to produce a reversal of polarity deficient machine, in which case it will run as a motor, sup none of its share of the current; but, on the contrary, mal



additional load for the other machines and perhaps ca costly interruption in the operation of the plant.

The method of proceeding when one machine is supplyi rent and it is desired to connect another up with it is as it being understood, of course, that the switches belon machine No. 2 are open: First, start up the engine of No. turn its rheostat till its pressure is the same as that of bars or perhaps one-half volt higher. Then close the sin switch in the equalizer circuit, shown dotted, and finally c machine's double-pole switch which connects it to the b Its ammeter reading will then increase, and the rheostat of the two machines are moved till the ammeters read a the machines are the same size) and the voltage of the bu correct. After that the machines will need little attentio one drops in speed a little current will be sent around i coil from the other machine through the equalizer circ keeping up its voltage. Instead of a two-pole switch in the d a single-pole switch in the equalizer lead, a ritch is frequently employed. In this case the middle blade is ıed for the equalizer wire, and is so adjusted that it closes .e equalizer circuit just before the other two blades close their rcuits.

This method is generally satisfactory, although it does not ıualize the load so perfectly as the following method, devised r Mr. Edwin R. Keller. This method differs from the revious one in that it will be seen that this is accomplished r connecting the beginnings of all of the series coils to an ctra bus bar, to which is connected also one brush of each achine, instead of connectıg the series windings diıct to the brushes and the ınctions of these to the ıualizing bus bar, as in ramme's method.



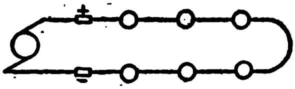
By arranging the connecons in this manner it is vident that the currents in ıe series coils of the machines will, at all times, be proportional ı the capacities of the machines, provided the resistances are proortioned in such a way that the drop of potential from the rushes of all the machines to the bus bars will be the same at full ıad.

The diagram shows how this method would be arranged at the witch-board. The mode of operation would be as follows: Whenver it is desired to throw in an additional machine the single-pole witch is first closed. This completes the series field circuit, and e immediately have a current in the series coils of the new ıachine, which will be proportional to its capacity. The rheostat ı the shunt circuit is then adjusted until the new machine generıes the desired electro-motive force. After this is done the main vitch may be closed without producing any further disturbance ı the electro-motive force of the system.

It has these disadvantages, however: it necessitates an additional conductor from the dynamo to the switch-board, an over, the full current passes through the conductors, whi replace the equalizer. Hence, the first cost is somewhat in and, further, a certain amount of energy is lost in hea conductors.

Systems of Distribution.—There are two common ments of circuits, called respectively the *series* system *multiple* or *parallel* system.

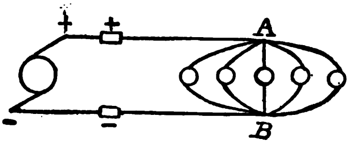
Series System.—In this system, which is the simpler, ductor starts from the positive brush of the generator, the positive bus bar of the switch-board, then out throug lamps one after another, then to the negative bus bar, an back to the negative brush of the machine. Such a circ commercially satisfactory n *constant current* circuit. throwing on or off lamps n change the value of the cu the lamps burn at thei brilliancy only when a cer rent flows through them. When lamps are thrown on, t ance of the circuits is increased, and to maintain the sam the electric pressure must be correspondingly raised. accomplished by a special regulator on the dynamo, as p explained. The pressure between the terminals of the d therefore proportional to the number of lamps burning. dinary 2000 candle-power street arc requires a pressure 50 volts between its terminals to force the proper cur ampères) through it, a circuit of 100 lights would hav ure at the machine terminals of about 5000 volts, an e dangerous pressure. The lowest voltage incandescent commercial use require about 50 volts also, so that it i that a series distribution is necessarily a high-pressure tion, and therefore dangerous. It has the further disa that an interruption of the circuit at any one point is of the whole circuit, and will put out all



Series System.

or these two reasons it is used only in outdoor distribution, here the wire, being on poles, is out of the reach of any one, nd where any breaks in the circuit are quickly found and reaired. Its chief advantage is that, being a high-pressure sysem, it transmits energy with a small loss over comparatively mall conductors.

The Parallel System.—In this system the current from the ynamo is divided and flows through the lamps, and afterward e separate currents are joined together and flow to the dynamos. f the resistances of the lamps re the same and that of the ires connecting them to A B lso the same, the currents hrough all the lamps will be like. By Ohm's law the current through any lamp is qual to the pressure or voltage between A and B divided by the esistance of the lamp. Now suppose one lamp is turned off; ill the brightness of the others be affected? Not if the voltage etween A and B is kept constant, for the resistance of each lamp s a constant, having no relation whatever to the fact that other amps are turned on or off. Therefore the current through each f the remaining lamps is just the same as it was before the one amp was turned off. And as the brilliancy depends strictly upon he current, it is likewise unchanged.

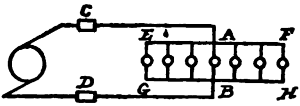


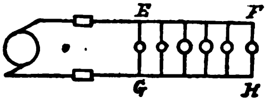
Parallel System.

The parallel system is therefore a constant potential or *constant-ressure* system, and also when distributing direct to lamps a low-ressure system. In practice the pressure between A and B is not ept quite constant; but so long as the variation is not more than or 3 per cent. it is not noticed by the eye.

The arrangement can, therefore, be somewhat modified so as to ive wire, as in these two figures. The wires E A and D B are lled *feeders*, the wires E F and G H are called *mains*, and the ires leading from the mains to the lamps are called branches.

In the first figure the middle lamp will burn a little brighter

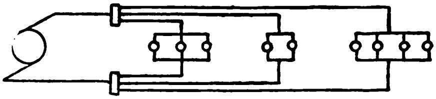




than the others, the two end ones being the dimmest, owing t loss of pressure in the main tween *A* and *E* and *B* and one side and *A* and *F* and *B* *H* on the other side. This los be reduced to a point as l desired by increasing the si the mains.

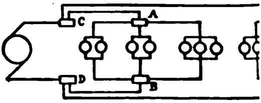
In the second figure the between *F* and *H* is the dim and that between *E* and *G* the brightest. This second arr ment is not as good as the first, as for a given size of wire is a greater difference of brilliancy between the brightes dimmest lamp.

The third figure shows a somewhat less simple distrib where more than one feeder-circuit leaves the switch-board



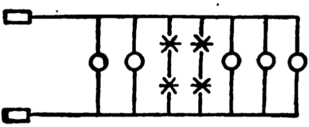
such systems the three feeders will probably be of differen wires, according to their length and the number of lights carry. They will be calculated so that the pressure lost on is the same.

The fourth figure shows an arrangement very common in ern buildings where it is desired that all safety devices, s fuses and circuit-breakers, shall be placed in closets. *A* and *B* here represent small bus bars on a small switch-board, or panel-board, as it is generally called, from which run the circuits for a single floor or perhaps a large room. *K* and *L* represent bus bars on another panel r floor. Separate feeders run to each, and on



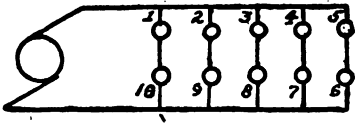
ced the fuses for each separate circuit running from the bus s. There would thus be on the panel-board *A B* six fuses, two each of the three circuits leading from the bus bars.

Modified Systems of Distribution.—It is very common in allel systems to put two lamps in series with each other, and n connect them to the mains, ecially when arc lamps are d. The reason is that arc ps of the *open arc* type re- ire only about 50 volts at

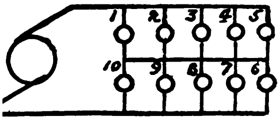


ir terminals, while most incandescent distribution is at 110 ts. We should, therefore, be obliged, if only one arc were to be d, to put in series with it a considerable resistance, so as to use the surplus 60 volts in forcing current through the resistance.

Three-wire System.—An extremely important modification is Edison three-wire system, which is a device for obtaining the vantages of distributing at) volts instead of 110, ich, as we shall see, intro- ces a great saving in wire, hout its accompanying dis- vantages of greater pressure

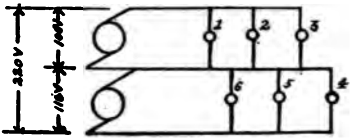


the lamps. If we put two 110 volt lamps in series with each ier and then connect them across the mains running from a 220 lt dynamo, we shall have a 220 volt distribution system, using) volt lamps, which will work perfectly satisfactorily until the ment of some lamp breaks or till some one turns it off. Then mate to that lamp, the one which was in series with it, will be extinguished. To overcome this a wire may be added as shown; but now if lamp 6, say, be turned off, the current for lamps 1, 2, 3, 4, and 5 must now pass through four lamps, so that 7, 8, 9, and 10 will



n *with excessive brightness* and will be quickly spoiled. To

avoid this objection the following arrangement of Edis
Two 110-volt machines are connected in series and t
or neutral wire is connected to their junction. When
number of lamps a
on each side of t
wire there is no cu
ing through the n
the same current flo
each machine. W
is turned out, for example, the lower machine suppli
current necessary for lamps 5 and 6, while the upper c
supply the same as before, the current for one lamp re
the upper machine over the neutral. If all lamps c
were turned out, the machine on that side would furni
rent, and the other machine would continue to work
It is not necessary to make the neutral so large as
wires, although this is usually done. Where it is de
able to change quickly from a three-wire to a two-w
the neutral is made twice the size of either outside
switch is put in which when thrown to a certain positic
the two outside wires together, so that they act as one
circuit under the new arrangement, while the neutral
other side.



Size of Conductors.—We know from Experiment
when an electric current traverses a wire it heats it mc
depending on the strength of current and the materi
size of the wire. This heating represents, of course, so
waste of the electrical energy of the current, and the
this loss in *watts* is equal to the square of the current
by the resistance of the conductor, or, in brief, C^2R, or
The loss of pressure—that is, the amount necessary tc
rrent C against the resistance R—is, from Ohm's l
tors must be large enough so that they will not
safe amount (underwriters allow a rise in te
above the surrounding air, it being cons

a greater degree of heating would injure the insulating covering of the wire), and also that the loss in pressure is no greater than the nature of the service will permit. The sizes are calculated, first, to meet the pressure-requirement, and then by looking in the table of safe carrying capacities we find whether the size calculated is large enough to meet the underwriters' requirements. It generally will be, except for short distances.

The allowable loss of pressure on wires is a matter which requires careful thought and considerable calculation to secure the best results. This is especially the case when the circuits supply incandescent lamps, the requirements for which are much more severe than for motors or arc lamps. Some general principles will be laid down, which if followed will lead to satisfactory results. The pressure at any lamp should not vary more than 2 to 4 per cent. under any variations in the number of lamps burning; 2 per cent. would represent a good result, and 4 per cent. only a fairly satisfactory one.

If there is but one feeder from the bus bars, we can obtain the result of 2 per cent. more easily in two ways. The first one and the simpler one is to use such size of wires that the loss of pressure, or *drop*, as it is called, between bus bars and lamps is only 2 per cent. of the voltage of the machine, which we will suppose to be 110 volts. Of the 2.2 volts allowable, we would use 1 volt on the feeder, ½ volt on the main, and ½ volt on the branches in many cases; but if the mains or branches were very short it would be better to use up only ¼ volt on each and 1½ volts on the feeder. We would then need to keep the machine at constant speed, giving constant pressure at the branches, and the desired result would be obtained.

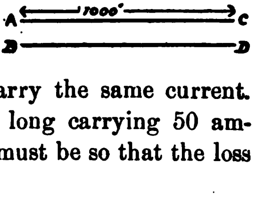
An equally good result can be obtained much more cheaply by allowing on the feeder a drop of, say, 4 per cent., or 4.4 volts, and 1 volt on the mains and 1 volt on the branches; and instead of keeping the voltage of the machine constant, raise it in proportion to the *reading* of the ammeter. When only a small current *flows over the* feeder, of course the loss of pressure is no appreciable and the rheostat of the machine would be turned so that the voltmeter reads 110. When all the lamps are burning we get the full drop on the wires, and the machine should be made to give 114.4 volts, thus giving at the junction of feeders and mains a voltage of 110. There being a loss of 1 volt in mains and 1 volt in the branches, the most distant lamps will burn under a voltage of 108. We have thus a variation in voltage at the lamps of only 2 per cent., and have used much smaller wires, the feeders being only one-quarter the area and the mains and branches only one-half what they must be by the first method. If a simple shunt machine were used, it would be necessary to move the rheostat handle to get the desired rise in voltage when the load increases, and this would require a great amount of attention. But a *compound* machine *over*-compounded 4.4 per cent. will automatically give the desired pressure of 114.4 at full load if the engine does not slow down. Practically the over-compounding would be made about 6 per cent. to make up for a reduction in engine-speed of about 2 per cent. from no load to full load. In the above case even more drop might be allowed—as much as 10 per cent., and for very long distances perhaps more, the exact percentage which is most economical requiring a calculation not coming within the scope of this book.

When there is more than one feeder the allowable drop is, in general, much less, for when one feeder is fully loaded the other may be only lightly loaded. On the first the lights would burn much less brightly than on the second, on account of the loss of pressure on the first being at its greatest value, while on the second there is but little loss.

If the feeders were all loaded to the same degree—that is, if they were all half-loaded at the same time, three-quarters loaded at the same time, and so on—we could still allow a large drop and get satisfactory service; but this is not generally the case, so that it is rarely advisable to allow a total drop from switch-board to lamps of more than 3 or 4 per cent., although in spe- ly favorable cases 5 or 6 per cent. may be allowed.

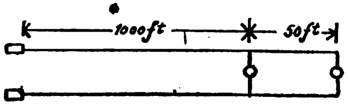
The division of the loss between the feeders, mains, and branches pends somewhat on the nature of each case. If the wires are be carried in an iron conduit, the branches should not in genal exceed No. 10. B. & S. gauge in size, to facilitate drawing. is not advisable, as a rule, to have more than eight 16 candle-)wer lamps on each circuit, so that by calculating the drop on e longest circuit we obtain that part of the total drop which n be allotted to the branches. On the mains it is rarely desirle to allow more than ½ or 1 per cent. The rest of the drop ll be assigned to the feeders, which are usually carried up some re-shaft or elevator-shaft where access may be easily had to em.

Calculation for a Given Drop.—Suppose that the feeders A C d B D are to carry 50 ampères at a loss of 4 per cent., the essure between C and D being 110 lts and the distance A C 1000 feet. e loss on A C is equal to the loss on D, as they are of equal length and carry the same current. e therefore have a conductor 2000 feet long carrying 50 amres, and we want to know what size it must be so that the loss pressure will be 4.4 volts.



By Ohm's law, in any wire circuit the current in any part of it equal to the pressure in that part divided by the resistance of at part, or $C=\frac{E}{R}$ or $R=\frac{E}{C}$, $E=4.4$, and $C=50$. There-e R, the resistance of the wire, $=\frac{4.4}{50}=.088$ ohm. This is the sistance of a circuit 2000 feet long; 1000 feet of such a size re would have a resistance of .044 ohm. Looking in the wire oles we find that a 4-0 wire has a resistance of .048 per 1000 t, so that it is a little too small, the amount being 4 parts in , or about 10 per cent. By taking a wire 10 per cent. larger cross-section we get the correct size.

Example.—Suppose it is desired to transmit energy to the two hts shown *in the diagram*, each being a 32 candle-power lamp *uiring 1 ampère*, the total allowable loss from bus bars to this farther lamp being 3 per cent. of the initial voltage, and t being a further requirei that no two lights on same circuit shall diffe pressure by more than 1 The initial pressure between the bus bars is 110 volts.



To meet the second requirement the allowable loss betweeı first and the second lamp is 1 volt in a length of circuit of 100 and a current of 1 ampère. By Ohm's law $R = \frac{E}{C} = \frac{1}{1} = 1$ That is, the wire must be of such a size that 100 feet will ha resistance of 1 ohm; 1000 feet of this wire will have a resist of 10 ohms. Looking in the wire tables we find that the ne size is a No. 20 B. & S. gauge. This wire is so small that mechanically unsafe to use, underwriters not allowing, on account, the use of a wire less than No. 14, 100 feet of which has a resistance of .25 ohm nearly. The drop or loss of pres in forcing 1 ampère through this resistance would be .25 × 1 = volt. According to the first requirement, the total allowable being 3 per cent. of 110, or 3.3 volts, this would leave as allowable drop from the bus bars to the *first* lamp 3.3 less .25 or 3.05 volts—call it 3 volts in round numbers. The lengt circuit is 2000 feet and the current 2 ampères. The resist must be $\frac{3}{2} = 1.5$. If 2000 feet is to have a resistance of 1.5 o 1000 feet will have a resistance $= \frac{1.5 \times 1000}{2000} = .75$ ohm. nearest size wire to this is No. 9, but as this is a little too sı and is moreover an odd size, we would use the next larger No. 8. Two thousand feet of No. 8 have a resistance of ohms, and the drop would be $2 \times 1.25 = 2.5$ volts to the lamp and .25 volt from the first to the second, making the drop from the bus bars to the last lamp 2.75 volts.

Advantages of Using High Pressure.—A given amoun *energy* can be transmitted with less loss in heating the line *if the* pressure is increased. An example will make this uppose it is desired to transmit 1100 watts power from one point o another 1000 feet distant. We may transmit it at any one of arious pressures, for example, 110, 220, 550, and 1100 volts. At 110 volts the current would be $\frac{1100}{110} = 10$ ampères. Suppose the wire used is a No. 7, having a resistance of closely .5 ohm per 000 feet. The total resistance of the line would be twice this, or ohm, since the total distance is 2000 feet. The loss in pressure is $E = CR = 10 \times 1$, or 10 volts. The total energy lost is $C \times C \times R = 10 \times 10 \times 1$, or 100 watts. Making similar calculations for transmission at the other voltages we can construct the following table:

Power transmitted in watts. $C \times E$	Volts at which transmitted. E	Corresponding number of ampères. C	Power lost in watts. C^2R	Volts drop in line. CR	Per cent. power lost. $C^2R \div 1100$	Per cent. volts lost. $CR \div E$
1100	110	10	100	10	11.	9.9
1100	220	5	25	5	2.75	2.27
1100	550	2	4	2	.0227	.363
1100	1100	1	1	1	.0009	.091

At 1100 volts the lost energy is 1 watt, while at 110 volts it is 100 watts. That is, by using a pressure 10 times as great the loss is only one-hundredth of what it would be at the lower pressure. We could therefore use a wire whose cross-section was but one-hundredth of what would be needed if we transmit at the lower pressure. The example shows clearly why it is that in long-distance transmissions, where the cost of the line is a large item, the pressures used are so high, reaching to 10,000 and even 20,000 volts.

Materials Used for Electrical Conductors.—Copper is used almost exclusively on account of its low resistance and fairly low price. It is soft-drawn for inside work, but hard-drawn for outside conductors on account of the increased tensile strength given by the hard-drawing process. Iron, which was formerly used largely on telegraph circuits, is used to a limited extent on short lines on account of its cheapness. It is never used for electric lighting or *power circuits.* Aluminum has many properties which *make it useful, and if* the cost of production should fall muc below its present figure, about 30 cents per pound, it will be an important rival of copper.

Insulation of Wires.—Telephone and telegraph wires strung outdoors on porcelain or glass insulators are not covered with any insulating material, and electric light and power wires in uninhabited or sparsely settled districts may be left bare likewise; but in towns and cities they are always coated with an insulating material. All wires for inside work are also covered. For outside work the wires have two braids (the best quality three braids) of cotton woven tightly around them and soaked in a fairly waterproof bituminous substance which serves to prevent the cotton braidings becoming wet. Such wires go under the name of double- or triple-braided weather-proof. A modified form of this wire, known as fire- and weather-proof, has been largely used for inside work. The inner cotton braidings are impregnated with white lead, which is a good insulator when dry and which makes the inner cotton braid very difficult to burn. The thin outer braiding, soaked in weather-proof compound, serves to keep the inner coatings dry. Both these wires are giving place to wires covered with rubber compounds, which, although much more expensive, are much better insulators. An outside braid is put around the rubber coats to protect them from abrasion. The quality of the rubber insulation on wires depends largely upon the percentage of pure rubber in its composition, which varies from 30 per cent. upward. The inner coat is made of either vulcanized white or red rubber in the best wires, as black rubber contains sulphur, which attacks the copper.

Cables.—Where the conductors are to be laid in water or in very damp places, as in underground work, or even the ducts leading from dynamos to switch-board, the insulated wires are encased in lead $\frac{1}{16}$ inch or more in thickness. Such conductors are known as cables. For such work use is made of other insulators besides those described above, such as fibre, jute, and paper, the thickness of insulation being increased in proportion to the size of wire and the pressure used.

Vire Gauges.—There are several different gauges in use, the dard in this country being the Brown & Sharpe (B. & S.). following table gives the principal gauges in use and their parative dimensions:

WIRE GAUGES IN MILS.

Numbers.	Roebling.	Brown & Sharpe.	Birmingham or Stubs.	New British standard.
000 000	460.	....	....	464.
00 000	430.	....	....	432.
0 000	393.	460.	454.	400.
000	362.	409.6	425.	372.
00	331.	364.8	380.	348.
0	307.	324.9	340.	324.
1	283.	289.3	300.	300.
2	263.	257.6	284.	276.
3	244.	229.4	259.	252.
4	225.	204.3	238.	232.
5	207.	181.9	220.	212.
6	192.	162.	203.	192.
7	177.	144.3	180.	176.
8	162.	128.5	165.	160.
9	148.	114.4	148.	144.
10	135.	101.9	134.	128.
11	120.	90.74	120.	116.
12	105.	80.81	109.	104.
13	92.	71.96	95.	92.
14	80.	64.08	83.	80.
15	72.	57.07	72.	72.
16	63.	50.82	65.	64.
17	54.	45.26	58.	56.
18	47.	40.3	49.	48.
19	41.	35.89	42.	40.
20	35.	31.96	35.	36.
21	32.	28.46	32.	32.
22	28.	25.35	28.	28.
23	25.	22.57	25.	24.
24	23.	20.1	22.	22.
25	20.	17.9	20.	20.
26	18.	15.94	18.	18.
27	17.	14.2	16.	16.4
28	16.	12.64	14.	14.8
29	15.	11.26	13.	13.6
30	14.	10.03	12.	12.4
31	13.	8.93	10.	11.6
32	13.	7.95	9.	10.8
33	11.	7.08	8.	10.
34	10.	6.3	7.	9.2

mil = *one-thousandth* of one inch.

e area in circular mils equals the square of the diameter in mils.

PROPERTIES OF COPPER WIRE.

ENGLISH SYSTEM—BROWN & SHARPE GAUGE.

Numbers.	Diameters in mils.	Areas in circular mils. C. M. = d^2.	Weights.		Resistances per 1 000 feet in International ohms.	
			1 000 feet.	Mile.	At 60° F.	At 75° F.
0 000	460.	211 600.	641.	3 382.	.048 11	.049 66
000	410.	168 100.	509.	2 687.	.060 56	.062 51
00	365.	133 225.	403.	2 129.	.076 42	.078 87
0	325.	105 625.	320.	1 688.	.096 39	.099 48
1	289.	83 521.	253.	1 335.	.121 9	.125 8
2	258.	66 564.	202.	1 064.	.152 9	.157 9
3	229.	52 441.	159.	838.	.194 1	.200 4
4	204.	41 616.	126.	665.	.244 6	.252 5
5	182.	33 124.	100.	529.	.307 4	.317 2
6	162.	26 244.	79.	419.	.387 9	.400 4
7	144.	20 736.	63.	331.	.491	.506 7
8	128.	16 384.	50.	262.	.621 4	.641 3
9	114.	12 996.	39.	208.	.783 4	.808 5
10	102.	10 404.	32.	166.	.978 5	1.01
11	91.	8 281.	25.	132.	1.229	1.269
12	81.	6 561.	20.	105.	1.552	1.601
13	72.	5 184.	15.7	83.	1.964	2.027
14	64.	4 096.	12.4	65.	2.485	2.565
15	57.	3 249.	9.8	52.	3.133	3.234
16	51.	2 601.	7.9	42.	3.914	4.04
17	45.	2 025.	6.1	32.	5.028	5.189
18	40.	1 600.	4.8	25.6	6.363	6.567
19	36.	1 296.	3.9	20.7	7.855	8.108
20	32.	1 024.	3.1	16.4	9.942	10.26
21	28.5	812.3	2.5	13.	12.53	12.94
22	25.3	640.1	1.9	10.2	15.9	16.41
23	22.6	510.8	1.5	8.2	19.93	20.57
24	20.1	404.	1.2	6.5	25.2	26.01
25	17.9	320.4	.97	5.1	31.77	32.79
26	15.9	252.8	.77	4.	40.27	41.56
27	14.2	201.6	.61	3.2	50.49	52.11
28	12.6	158.8	.48	2.5	64.13	66.18
29	11.3	127.7	.39	2.	79.73	82.29
30	10.	100.	.3	1.6	101.8	105.1
31	8.9	79.2	.24	1.27	128.5	132.7
32	8.	64.	.19	1.02	159.1	164.2
33	7.1	50.4	.15	.81	202.	208.4
34	6.3	39.7	.12	.63	256.5	264.7
35	5.6	31.4	.095	.5	324.6	335.1
36	5.	25.	.076	.4	407.2	420.3

There are two points in this table which will be found easy to reme *and very* convenient in practice—namely, that the resistance of 1000 fe *No. 10 is* almost exactly 1 ohm at 75° F., and that a change of three sizes e *halves* or doubles the resistance, according as we go up or down the tabl

STRANDS OF COPPER WIRE.

B. & S. gauge.	Circular mils.	Diameters.		Weights.		Resistance at 75° F. per 1 000 feet.
		Decimal parts of inch.	Nearest 32d.	1 000 feet.	Mile.	
....	1 000 000	1.152	1 3/16	3 050	16 104	.010 51
....	950 000	1.125	1 1/8	2 898	15 299	.011 06
....	900 000	1.092	1 3/32	2 745	14 494	.011 67
....	850 000	1.062	1 1/16	2 593	13 688	.012 36
....	800 000	1.035	1 1/32	2 440	12 883	.013 13
....	750 000	.999	1	2 288	12 078	.014 01
....	700 000	.963	31/32	2 135	11 273	.015 01
....	650 000	.927	15/16	1 983	10 468	.016 17
....	600 000	.891	29/32	1 830	9 662	.017 51
....	550 000	.855	7/8	1 678	8 857	.019 1
....	500 000	.819	13/16	1 525	8 052	.021 01
....	450 000	.770	25/32	1 373	7 247	.023 35
....	400 000	.728	3/4	1 220	6 442	.026 27
....	350 000	.679	11/16	1 068	5 636	.030 02
....	300 000	.630	5/8	915	4 831	.035 02
	250 000	.590	19/32	762	4 026	.042 03
0 000	211 600	.530	17/32	645	3 405	.049 66
000	168 100	.470	15/32	513	2 709	.062 51
00	133 225	.420	7/16	406	2 144	.078 87
0	105 625	.375	3/8	322	1 700	.099 48
1	83 521	.330	11/32	255	1 346	.125 8
2	66 564	291	5/16	203	1 072	.157 9
3	52 441	.261	9/32	160	845	.200 4
4	41 616	.231	1/4	127	671	.252 5

TENSILE STRENGTH OF COPPER WIRE.

B. & S. gauge.	Breaking weight. Pounds.		B. & S. gauge.	Breaking weight. Pounds.	
	Hard drawn.	Annealed.		Hard drawn.	Annealed.
0 000	3 310	5 650	9	617	349
000	6 580	4 480	10	489	277
00	5 226	3 553	11	388	219
0	4 558	2 818	12	307	174
1	3 746	2 234	13	244	138
2	3 127	1 772	14	193	109
3	2 480	1 405	15	153	87
4	1 967	1 114	16	133	69
5	1 559	883	17	97	55
6	1 237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

INSURANCE RULES FOR CARRYING-CAPACITY OF WIRES.

B. & S. gauge.	Half of current causing 72° F. rise.	National Electric Light Association.	National Board of Fire Underwriters.		Assoc. Factory Mutual Ins. Co.	English Board Trade.
			Concealed.	Open work.		
0 000	174	175	218	312	175	
000	146	145	181	262	145	
00	123	120	150	220	120	105
0	103	100	125	185	100	83
1	88	95	105	156	85	66
2	73	70	88	131	70	52
3	61	60	75	110	60	41
4	52	50	68	92	50	33
5	43	45	58	77	45	26
6	36	35	45	65	35	21
7	31	30	...	...	30	16
8	26	25	33	46	25	13
10	18	20	25	32	20	8
12	13	15	17	23	15	5
14	9	10	12	16	10	3
16	6	5	6	8	5	2
18	5	...	3	5	3	1

GALVANIZED IRON WIRE.

Numbers, B. W. G.	Diameters in mils.	Weights. Pounds.		Breaking weights.		Resistance per mile in ohms.		
		1 000 feet.	One mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	304	1 607	4 821	9 079	2.93	3.42	4.05
1	300	237	1 251	3 753	7 068	3.76	4.4	5.2
2	284	212	1 121	3 363	6 335	4.19	4.91	5.8
3	259	177	932	2 796	5 268	5.04	5.9	6.97
4	238	149	787	2 361	4 449	5.97	6.99	8.26
5	220	127	673	2 019	3 801	6.99	8.18	9.66
6	203	109	573	1 719	3 237	8.21	9.6	11.35
7	180	85	450	1 350	2 545	10.44	12.21	14.43
8	165	72	378	1 134	2 138	12.42	14.53	17.18
9	148	58	305	915	1 720	15.44	18.06	21.35
10	134	47	250	750	1 410	18.83	22.04	26.04
11	120	38	200	600	1 131	23.48	27.48	32.47
12	109	31	165	495	933	28.46	33.3	39.36
13	95	24	125	375	709	37.47	43.85	51.82
14	83	18	98	288	541	49.08	57.44	67.88
15	72	13.7	72	216	407	65.23	76.33	90.21
16	65	11.1	59	177	332	80.03	93.66	110.7
17	58	8.9	47	141	264	100.5	120.4	139.
18	49	6.3	33	99	189	140.8	164.8	194.8

WEATHERPROOF WIRE.

Numbers, B. & S. G.	Double braid.			Triple braid.			Approximate weights. Pounds.	
	Outside diameters in 32ds inch.	Weights. Pounds.		Outside diameters in 32ds inch.	Weights. Pounds.			
		1 000 feet.	Mile.		1 000 feet.	Mile.	Reel.	Coil.
0 000	20	716	3 781	24	775	4 092	2 000	250
000	18	575	3 036	22	630	3 326	2 000	250
00	17	465	2 455	18	490	2 587	500	250
0	16	375	1 980	17	400	2 112	500	250
1	15	285	1 505	16	306	1 616	500	250
2	14	245	1 294	15	268	1 415	500	250
3	13	190	1 003	14	210	1 109	500	250
4	11	152	803	12	164	866	250	125
5	10	120	634	11	145	766	260	130
6	9	98	518	10	112	591	275	140
8	8	66	349	9	78	412	200	100
10	7	45	238	8	55	290	200	100
12	6	30	158	7	35	185	.....	25
14	5	20	106	6	26	137	.....	25
16	4	14	74	5	20	106	.....	25
18	3	10	53	4	16	85	.....	25

STRANDED WEATHERPROOF FEED WIRE.

Circular mils.	Outside diameters. Inches.	Weights. Pounds.		Approximate length on reels. Feet.
		1 000 feet.	Mile.	
1 000 000	1½	3 550	18 744	800
900 000	$1\frac{13}{32}$	3 215	16 975	800
800 000	$1\frac{11}{32}$	2 880	15 206	850
750 000	$1\frac{5}{16}$	2 713	14 325	850
700 000	$1\frac{9}{32}$	2 545	13 438	900
650 000	1¼	2 378	12 556	900
600 000	$1\frac{7}{32}$	2 210	11 668	1 000
550 000	$1\frac{3}{16}$	2 043	10 787	1 200
500 000	1⅛	1 875	9 900	1 320
450 000	$1\frac{3}{32}$	1 703	8 992	1 400
400 000	$1\frac{1}{16}$	1 530	8 078	1 450
350 000	1	1 358	7 170	1 500
300 000	$\frac{15}{16}$	1 185	6 257	1 600
250 000	$\frac{29}{32}$	1 012	5 343	1 600

he table is calculated for concentric strands. Rope-laid nds are larger.

ire and weatherproof wire has about the same weight and *de diameter as* triple braid weatherproof.

CRESCENT RUBBER WIRE.

STRANDED CONDUCTORS.

Numbers, B. & S. G.	Circular mils.	Outside diameters. Inches.	Weights per 1 000 feet. Pounds.	Sizes of wires in strands. B. & S. G.	
				Regular.	Flexible.
....	1 000 000	1 7/16	3 690	8	12
....	900 000	1 11/32	3 370	8	12
....	800 000	1 9/32	3 020	8	12
....	700 000	1 7/32	2 685	10	12
....	600 000	1 5/32	2 345	10	12
....	500 000	1 1/16	1 885	10	14
....	450 000	1 1/32	1 728	10	14
....	400 000	1	1 560	10	14
....	350 000	15/16	1 378	10	14
....	300 000	7/8	1 155	10	14
	250 000	27/32	995	10	14
0 000	....	25/32	866	10	15
000	....	23/32	725	10	15
00	....	11/16	613	11	15

CRESCENT RUBBER WIRE.

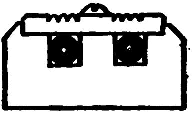
SMALLER SIZES.

Numbers, B. & S. G.	Outside diameters in 32ds of an inch.		Weights per 1 000 feet. Pounds.	Sizes of wires in strand. B. & S. G.	
	Solid.	Stranded.		Regular.	Flexible.
0	18	20	489	12	16
1	16	18	393	12	16
2	14	15	309	12	18
3	13	14	244	13	18
4	12	13	198	14	20
5	11	12	168	15	20
6	10	11	146	16	20
8	9	10	106	18	22
10	8	8	77	20	25
12	7	7	55	20	25
14	6	6	35	21	25
16	5	5	25	23	25
18	4	4	20	25	25

LEAD-ENCASED CABLES.

bers, S. G.	Circular mils.	Outside diameters. Inches.	Weights, 1 000 feet. Pounds.	Ampères causing 14° F. rise.
	1 000 000	$1\frac{13}{16}$	6 685	624
	900 000	$1\frac{23}{32}$	6 228	580
	800 000	$1\frac{21}{32}$	5 773	514
	750 000	$1\frac{5}{8}$	5 543	489
	700 000	$1\frac{19}{32}$	5 315	454
	650 000	$1\frac{9}{16}$	5 088	439
	600 000	$1\frac{17}{32}$	4 857	411
	550 000	$1\frac{1}{2}$	4 630	385
	500 000	$1\frac{7}{16}$	4 278	362
	450 000	$1\frac{3}{8}$	3 923	337
	400 000	$1\frac{11}{32}$	3 619	327
	350 000	$1\frac{5}{16}$	3 416	298
	300 000	$1\frac{1}{4}$	3 060	270
	250 000	$1\frac{3}{16}$	2 732	242
0	211 600	$1\frac{3}{32}$	2 533	221
0	168 100	$1\frac{1}{16}$	2 300	190
0	133 225	1	2 021	157
0	105 625	$\frac{15}{16}$	1 772	135
1	83 521	$\frac{29}{32}$	1 633	115
2	66 564	$\frac{7}{8}$	1 482	100
3	52 441	$\frac{25}{32}$	1 360	86
4	41 616	$\frac{3}{4}$	1 251	73
6	26 244	$\frac{11}{16}$	1 046	51

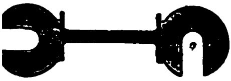
hods of Carrying Conductors.—These may be divided into ısses: *open work,* where the conductors are in plain sight; *ncealed work,* where they are hidden from view. Open s used only in mills, factories, and similar buildings, where ·ance is a secondary consideration. The wires are fastened celain insulators by means of tie wires. Wherever it is ıry to pass through a floor or partition the wires pass h porcelain or glass tubes placed in the partition or floor. work has the advantage of cheapness, and moreover any *ıre quickly detected* and repaired. Concealed work may *her subdivided into* moulding-work, porcelain-work, and



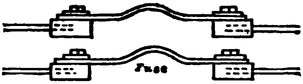
conduit-work. In moulding-work the wires are placed in g strips of wood of section similar t shown in the sketch, and are then co by a capping of wood which is screw As moist wood is not a good insulato work must not be used in damp plac underwriters do not permit its use in lofts or in any place is not on the surface. Concealed porcelain-work is precise open work, except that, being out of sight, it is not so neatl Conduits made of various materials have come into use the last few years. The fundamental idea of a conduit is vide a raceway which may be installed during the consti of the building and into which wires may be afterward In case of any injury to the wires after they are in place it pected that they can be easily withdrawn and replaced l wires. A suitable conduit should, therefore, be strong eno protect wires within it from the accidents that are liable t to it, such as by hammering, jarring, etc., and it should al a smooth inside surface, so as not to scratch the insulation the drawing-in process. Moreover, it should not be attac moisture, cements, or plasters. The early conduits, such a ducts, brass-armored fibre-ducts, and circular-loom condu not fulfil these requirements, and have almost entirely way to an iron or steel conduit. At present these consis iron or steel pipe lined with fibre, wood, or rubber con partly to secure a smooth inside surface and partly to insulating the wire. It is probable, however, that this ins lining will be done away with either by improving the r of making the pipe so as to secure a smooth inner surfac means of an enamel. If these pipes are made thick enough sults are entirely satisfactory. In a conduit system the and negative sides of a circuit are carried both in one tube, for alternating currents an excessive drop in pressure occu *self-induction* due to the iron unless this is done. It is, m to do this anyway, because any troubles in th s, such as overheating due to short circuits or leakages, are ined within the pipe and do not give rise to fires in surround- woodwork. Bends are made by elbows and couplings or by fully bending the pipe. Such a system is practically obliga- in modern fireproof-constructed buildings, and is used alto- er in spite of its high cost.

ppliances Used on the Line.—A considerable number of de- s have come into use on electric circuits for making the dis- ition of electrical energy as convenient and as safe as possible. ong these are fuses, cut-outs and circuit-breakers, switches, ets or receptacles, insulating joints, dimmers, etc.

he fuse is used to prevent wires being traversed by a current re the safe carrying capacity. It consists usually of a small e of an alloy of lead and zinc soldered to two copper termi- slotted so as to admit the stud. They are inserted at every t in a circuit where the wire diminishes in size and are placed ie circuit of the smaller wire. The figure shows how this is done, larger wire being led into two blocks having each a threaded



Fuse.

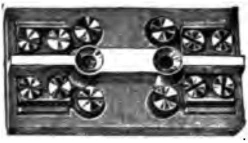


No. 10. No. 8.

carrying a nut and washer. The smaller wires run into simi- blocks and the fuses are put on with their copper terminals ped securely under the nuts. The safe carrying capacity of 10 wire for concealed work, as given by the underwriters' e, is 25 ampères. The fuses used ought to be such that they ld melt and thus interrupt the passage of current over the No. vire in the above cut if any accidental leakage should allow e than 25 ampères to flow through it ; but as practically the s made of a certain size and intended to blow at this current- *ngth, may blow at a* smaller current-strength or a larger one, *way of 25 to 30* per cent. is allowed, and a fuse marked t blow at 25 ampères is one which it is expected will actually mel at 30 to 35 ampères.

The uncertainty of the action of fuses, especially in large si has led to the use of circuit-breakers, which were describ under the heading "Switch-boards." In the opinion of th authors, the use of fuses above 50 ampères is extremely undes able unless much greater care is taken in testing and using the than is the case with the ordinary commercial product.

Cut-outs.—The combination of fuse-blocks, studs, and scre or nuts, with convenient terminals for holding the wires wh mounted on a piece of slate, marble, or porcelain, is called a cu *out.* When the smaller wires continue in the same general dire tion as the larger, the pattern used is called a main line cut-ou and when the directions are at right angles the pattern is know as a branch cut-out. Cuts of both styles are shown. They shou be furnished with a cover of slate, porcelain, or mica, so that the fuse blows when some trouble occurs there will be no dang of injury or defacement by the particles of melted fuse-metal.


Main Line Cut-out.

Branch Cut-out.

Switches in their action correspond to valves in that they a used to throw on and shut off current. They differ from valv in that they either shut it off entirely or throw it on entirel there being no intermediate positions by which the strength of cu rent can be regulated. If this is desired, a *dimmer* must be use

Switches are *single pole* if one side of the circuit is opened ar closed by them; *double pole*, if both sides are controlled: an *triple pole*, if, as in some cases, the same handle is made to contr *three* switch-blades, which open and close three wires. A do switch is one by means of which the blades can be thrown :onnection with either of two circuits. It is frequently used a building is to be lighted nost of the time by its own , but in case of emergencies be lighted by some other

Single-throw Switch.

Double-throw Switch.

. In such cases the hinged blade is connected to the circuit è buildings, the upper terminals to the plant of the build- ınd the lower terminals to the outside plant, and *vice versa.*

ıife-blade switches are those above illustrated, in which the ıct-making piece has a shape somewhat like a knife-blade and o hinged at one end.

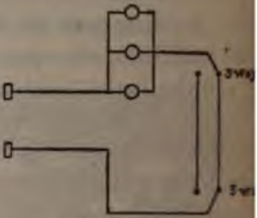
ap switches are switches specially shaped to secure greater ıactness, and are also provided with a spring which makes notion of the contact piece positive. Once started, it goes r to the position of *make* or to that of *break*, it not being ble for it to stop at a position of par- r imperfect contact. Snap switches rovided with covers which prevent ns from accidentally touching the ıctors and thus receiving an electric :. For this reason they are used in s and nearly all locations except on h-boards and panel-boards. They ıade in sizes up to 100 ampères; but ıy current above 25 ampères it is generally advisable to use *-blade switches,* as the latter are much less liable to give *e from imperfect* contacts, broken parts, etc. To secure

Snap Switch.

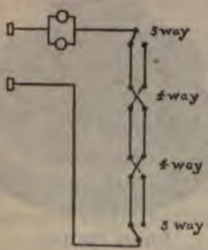
switches which shall be inconspicuous a specially designed sn switch is made so that its cove ing plate can be set flush wi the wall. It is operated turning a handle in some p terns, or by pushing one butt to open and another to cl the circuit in another patte The cut shows the style adopt by the company which first ma the flush type of switches.

Flush Switch.

3-way switches are employed where it is desired to turn lam on or off from either of two points. The method of connection is shown in the diagram, a 3-way switch being placed at each point. The figure shows the lamps burning. Throwing either switch will extinguish them, after which a movement of either will again light them.



4-way or Commutation Switches.—By means of these two 3-way switches it is possible to control lamps from any one any number of points. In the diagram the lamps are sho burning. If any switch is turned into dotted position, the lamps will be ex guished. If now any switch is turned, t will burn again.



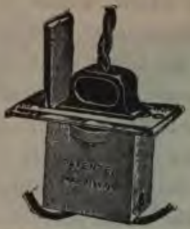
Chandelier Switches.—Another spe switch is so arranged that by turnin one-quarter round one light on the ch delier will burn, another quarter lights ditional lamps, a third-quarter turn ca *all the* lamps to burn, while the fourth-quarter turn extingui *all of* them.

Contact Surfaces.—The relative quality of switches de rgely upon the quality of workmanship. The parts must, se, be designed large enough to carry the current without able heating. It is usual to allow, where the current through solid copper, a current-density of 1000 ampères iare inch of cross-section, and for brass, whose specific re- is much greater than that of copper, a less density depend- the percentage of copper in the brass. Where the current through the contact surface of two pieces, as from blade to ie most careful workmanship is needed. The blades should ind in and should touch along the whole surface of the clip. this is the case a current of about 100 ampères per square contact surface can be safely allowed, but for the ordinary anship found on most switch-boards 75 ampères per square ould be safer. Where the contact is made between two pieces smoothly faced and parallel and held together by a proper size, a density of 200 ampères per square inch of con- rface can be allowed.

ets are mechanical arrangements for holding a lamp-bulb but still allowing it to be easily withdrawn. Electrically ake contact between the two wires o them and the terminals of the lament. Key-sockets have in ad- a tiny single-pole snap switch interrupts this contact. They are of different styles to fit the various ases, the principal of which are lison, Thomson-Houston (T.-H.), estinghouse.

Westinghouse Key-socket.

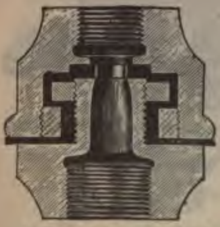
eptacles.—A receptacle originally used socket made so as to screw to ll or ceiling. Latterly the term in- a very useful device called the at- nt-plug, which is employed where esired to use current temporarily have a flexible connection between the circuit and the lamp, motor, or other device in which current is to be used. The Chapn receptacle consists of a porcelain box with two terminals into wh the circuit wires are led. These terminals are each in connec with a flat piece of copper. The *plug* to which the flexible ductors are attached has also two terminals, likewise conne through fuses to flat contact pieces. When the plug is pushe the receptacle contact is made and the flexible cords and appar attached are connected to the circuit. When out of use the is pulled out and a hinged lid drops down and covers the conts



Chapman Receptacle and Plug.

Plug.

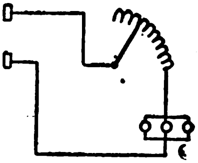
The flexible cord, while extremely convenient, is one of least safe parts of an electrical system. A cut-out contai fuses is therefore always placed at its junction with the main cuit. With the receptacle this cut-out is in the plug. In cases it is a small porcelain affair of various shapes, and is kn as a K. W. or a *ceiling rosette.*



Insulating Joint.

Insulating joints are used wherever tures are combination gas and electric. are made in two parts insulated from other. The upper part is connected trically to the gas-pipe system, since screwed on to the end of the gas-pipe. lower side is likewise connected electri to the fixture, since the latter is scr into the joint; but owing to the insul piece the fixture is insulated from th pipe system. Therefore an accidental contact between a con ıe fixture does not connect the conductor to the earth through ıs-pipe system.

nmers.—A dimmer is an adjustable resistance or rheostat is placed in series with the group of lamps whose brilliancy esired to vary. Turning the dimmer e one way throws more resistance in with the lamps, and therefore cuts the current flowing through them, ı, of course, makes them burn more . Turning the handle the other way he opposite effect. They are princi- used in theatres and halls. Since they cut down current by ıosing their own resistance, they are heated up to a consid- ɜ extent and should be mounted like any rheostat on slate ırble, or some incombustible substance.

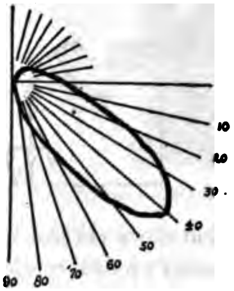


CHAPTER XXXIII.

THE ELECTRIC LIGHT.

ɔ **Lamps.**—When a current from a source of some 50 volts ıre is passed through the junction of two pieces of carbon, hese pieces are then separated about $\frac{1}{16}$ inch, an intensely ınt white light is produced, which is called the electric arc. ıe intense heat produced the carbon on the positive side is ·ized. Part is burned in the air, while a small amount is ɔd over to the negative carbon. There it is burned away ıer with the carbon already there, the rate of consumption ɜ positive being, roughly speaking, twice as great as that of ɜgative.

ıtribution of the Light.—The intensity of the arc varies ly when looked at from different directions. Measurements show that if plotted, letting distances from the arc represent candle-power at that angle, the curve showing variation brilliancy will be for direct current lamps approximately shown, the upper carbon being as usual the positive carbon.



Rating of Lamps.—Lamps are rat in candle-power according to their b liancy in the angle of greatest b liancy. Thus the ordinary street la rated at 2000 candle-power gives t brilliancy only at an angle from t horizontal of about 45 degrees. any other angle its brilliancy is less, a the average will not be much over 8 candle-power. Such a lamp requires current of 9.6 ampères and about 45 50 volts, and a lamp using such current and pressure that the product is 450 watts may be considered commercially a 20 candle-power lamp.

Classification.—Lamps may be classified in several differe ways: 1. According to the kind of distribution-system for whic they are intended, as constant potential arc lamps and series a lamps; as the latter are in general used now only by central st tions, their description will be omitted. 2. According as they a to be supplied by direct or alternating current, into direct curre arcs and alternating arcs; only the former will be considered 3. According to the degree of enclosure of the arc, into open ar and closed arcs.

Requirements of All Arc Lamps.—All lamps to be comme cially satisfactory must do two things: They must strike the arc— that is, after current has commenced to flow they must automati ally draw the carbons apart so as to *strike* the arc. They mu also regulate—that is, as the carbons burn away they must b automatically fed together, and the feeding of one must not ap preciably affect the brilliancy of others.

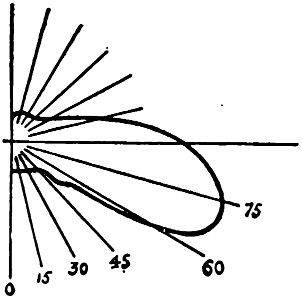
Constant Potential Arcs.—The mechanism of such lamps is o e simplest description unless several are intended to run i

ies. The current coming from the line to the positive lamp-
minal passes through a coarse wire coil and then through a
ain or brush contact to the upper carbon, through the upper
d lower carbons, and back through a wire resistance, which can
varied, to the other terminal of the lamp, and thence to line.
e passage of current through the coil lifts an iron armature
core, as the case may be, to a certain distance depending on
strength of the current. This armature lifts a clutch-device
ich raises the upper carbon. The arc is thus struck and the
np continues to burn, the two carbons being gradually con-
ned and the arc becoming longer. As the arc lengthens its re-
ance becomes greater and the current less. This allows the
nature to drop down a little, and the clutch tripping against a
p lets the upper carbon slide through a little, thus shortening
arc. The moment the arc has been shortened sufficiently to
rease the current enough to lift the clutch off the tripping-stop
feeding of the carbon ceases and the lamp continues to burn
the arc again becomes too long. When several lamps are to
operated in series they will not all feed at the same time, so
t the action of one would interfere with the others unless some
ferent arrangements were introduced. In such cases an addi-
nal magnet with fine wire coil is connected as a shunt around the
, and its armature arranged so that when lifted to a certain
int it makes the clutch feed. As the arc lengthens its resist-
ce increases, and also the pressure between its terminals. Hence
re current is sent around the fine wire coils, raising their arma-
re and starting the feeding mechanism.

Open Arcs.—When the carbons burn in open air or in a globe
considerable size (usually 12 inches in diameter) to which air
s free access, they are said to be open arcs. Under such cir-
mstances the consumption of carbon is quite rapid, an upper
rbon, 12 inches long by ½ inch diameter, lasting about seven
urs, while the lower or negative carbon lasts about twice as
ng. To secure a longer life, the device was tried of enclosing
arc in an air-tight globe or in a globe filled with a gas like

nitrogen or carbonic acid, in which the carbon would not l Such lamps are called closed arcs.

The closed arc, working in a vacuum, was not a success it has been found necessary to give a slight access of air to burn the particles of carbon that are detached. The of combustion is, however, so slow that the lamps require ming only once in 100 or in 150 hours, as against once hours for the open arcs. The length of the arc which will quietly is much greater in the closed arc, so that the volts higher, rising to 80 or 90 volts, with a corresponding redu of current to about 5 ampères for the nominal 2000 candle-p lamp. This is quite an advantage, as it is not necessary t two lamps in series across 110-volt mains to avoid an exc waste of energy in a resistance coil. Owing to the use o globes, one of which is us opalescent, there is a more distribution of light than for arcs, as will be seen by comp the accompanying figure wit one preceding.



Incandescent lamps consist carbon filament attached to num wires, which is mounted glass globe from which the ai been exhausted and which is s up so as to exclude air. The platinum wires serve to conne filament to the terminals of the lamp base. The vacuum is as perfect as possible, so that there may remain no air insid globe in which the highly heated filament would burn away.

The filament is made by taking a slender piece of some rial consisting largely of carbon, such as bamboo, silk, pap cellulose, and heating it intensely in a furnace so as to driv all the other material, leaving a very nearly pure carbon tl *In order to* smooth out the roughness and make its section un *at all points*, a current is passed through it large enough to nearly a white heat in an atmosphere of some hydrocarbon, like l gas. This causes carbon to be deposited most largely at the ttest points, which are those of the smallest cross-section. The ment is then attached to the platinum leading-in wires and ced in the globe. A mechanical air-pump exhausts the air m the globe, and finally, by passing a strong current through filament, the latter, heated to incandescence, burns away the nant of oxygen remaining. The bulb is then sealed up and

Edison.

T-H.

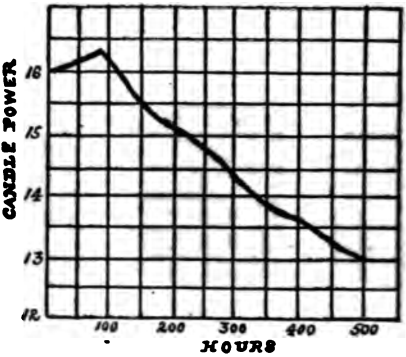
Westinghouse.

platinum wires connected to the lamp-base terminals, These of different styles, the three most common being shown in accompanying cuts. Finally, the lamps are tested to see at at voltage they will give the candle-power for which they are nded.

he candle-powers ordinarily made are 8, 10, 12, 16, 20, 24, 50, 100, and 150, though it is unusual to find the last two s, arc lamps being substituted for them. As the lamp conies in use its candle-power gradually diminishes, owing to the osition of carbon from the filament on to the walls of the e, the layer of carbon absorbing the light rays, so that after w hundred hours' burning the lamp must be replaced by a one. The curve on the next page, obtained from tests on mercial lamps, shows this action plainly.

he voltages for which lamps are usually made are as follows: n 50, 51, 52, and so on up to 60; 70, 71, 72, and up to 80; *101, and up to 125;* and from 220 to 250. In the voltages

above 125 only lamps of 16 candle-power and over are m
with the smaller candle-powers the filament would be too
be mechanically of sufficient strength. The use of 220-volt
as previously pointed out, makes the wiring system much cl
and they are being extensively employed, although it is n



sible at present to make a 220-volt lamp of 16 candle-po
good as a 110-volt lamp of that candle-power.

Life and Efficiency of Lamps.—A 16 candle-power lan
110 volts requires a current of from .38 to .6 ampère to h
hot enough to give 16 candle-power, according to the natur
cross-section of its filament. The one with the finer filame
quiring but .38 ampère, would, however, not last nearly as
as the one requiring .6 ampère. .38 ampère at 110 volts is
to 41.8 watts. Dividing by 16, we have 2.6 watts power req
per candle-power produced. This figure is called the effic
of the lamp. The smaller the power required to produc
candle-power the more efficient the lamp. Unfortunately, g
efficiency is accompanied by a corresponding shortness of li
will be seen by the following table of approximate values
be expected with good lamps:

Efficiency. Watts per candle.	Life-hours.	Watts per 16 c. p. lamp.	Ampères for 16 c. p. 110-volt lamp.
2.6	400	41.8	.38
3.1	600	49.6	.45
3.6	800	57.6	.52
4.0	1000	64.0	.60

The choice of efficiency which it is advisable to use in a given case depends upon the cost of power. If coal is cheap, it pays to use a low efficiency and long life. If coal is dear, the high efficiency lamp should be used, provided the speed regulation of the engine is good enough to prevent fluctuations in the voltage of the dynamo, it being understood that any rise in voltage above that for which the lamp is intended shortens its life very seriously. Of course, where all the exhaust steam of the generator engine is used in steam heating it is desirable to use the low efficiency and long life lamps.

Distribution of Light.—In calculating on the distribution of lights, we must take into consideration the character of the space to be lighted, its dimensions, the color of the walls, and the brilliancy required. As a measure of the brilliancy it is often convenient to make use of a unit of intensity of illumination, called the candle-foot (written c. ft.), which is the intensity of illumination produced by one standard candle at a distance of one foot. As is well known, the intensity of illumination from a given source varies inversely with the square of the distance; that is to say, one candle at 4 ft. would give an intensity of illumination of $\frac{1}{16}$ c. ft.; and at a distance of 2 ft. would give $\frac{1}{4}$ c. ft. A 16 candle-power lamp at 1 foot would give 16 c. ft., at 2 ft. would give 4 c. ft., and at 4 ft. would give 1 c. ft.

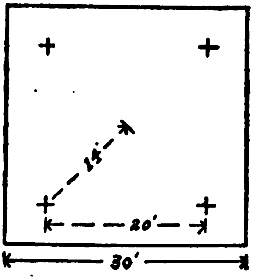
The number of candle feet at any point is found as follows: If due to one lamp, divide the candle-power of the lamp by the square of the distance in feet from the lamp to the point in question. If there are several lamps at equal distances, divide their total candle-power by the square of the distance. If they are unequal distances, compute the candle feet due to each add them together.

Effect of Height of Lamp.—Suppose that we have at the he of 7 feet above the floor four 16 candle-power lamps; the illı nation immediately beneath the lamps on the floor would be $\frac{4}{7}$ $= \frac{64}{49} = 1.2$. With lamps 8 feet high the illumination would l = 1 c. ft.; at 9 feet it would be $\frac{64}{81}$ = .79 c. ft.; at 10 feet it w be $\frac{64}{100}$ c. ft., or practically one-half what it would be at 7 In this calculation we have evidently neglected the effect o flection, but the figures give a fair idea of the effect of pl the lights at different heights. Generally the lamps are pl at a height of 7 feet or 7 feet 6 inches above the floor.

Effect of Color and Surface of Walls.—The following gives the percentage of the total light cast upon different faces which is reflected by those surfaces. The lighter c reflect a large amount of light and the dark ones almost ı

White blotting-paper	82	Plane deal (dirty)	
White cartridge-paper	80	Yellow cardboard	
Yellow wall-paper	40	Parchment (1 thickness)	
Blue paper	25	" (2 ")	
Dark brown paper	13	Yellow painted wall (clean)	
Deep chocolate paper	4	" " (dirty)	
Plane deal (clean)	40–50	Black cloth	

Effect of Arrangement.—We will first consider this ter, neglecting the effect of walls and ceiling. We will pose that it is desired to secure a certain minimum illuminat that is to say, a certain number of c. ft. at that point of room which is least illuminated.. Suppose, for example, tha take (see figure on page 743) a room 30 feet square, and the lights are placed at four points in the room, each of points being 5 feet perpendicularly distant from two walls; *four points* would then, if joined together, form a square w *side is 20* feet and whose diagonal is about 28 feet. The *illuminated* point would be at the intersection of the dia ing a point on this intersection at the same height from the as the lamps are hung, if we ed two 16 candle-power lamps at corner the illumination at the re would be



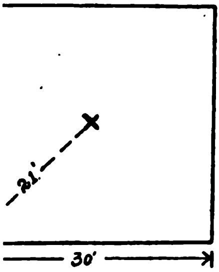
$$\frac{2 \times 4 \times 16}{14 \times 14} = \frac{32}{49} = .65 \text{ c. ft.}$$

illumination at the corners equals

$$\frac{32}{7 \times 7} = \frac{32}{49} \text{c. ft.},$$

idering only the two nearest lamps.

ight lamps at centre. If, as in the figure, we mass the eight s at the centre, the minimum illumination, which now will be at the corners of the room, will be



$$\frac{8 \times 16}{21 \times 21} = \frac{128}{441} = 295 \text{ c. ft.},$$

which is very much less minimum illumination than we obtained before, and which shows very clearly that for the given expenditure of energy we will get a much greater minimum illumination as well as a more uniform illumination by distributing s, instead of massing them at one point.

nount of Light Required.—This depends on the purpose for h the room is used and the color of the walls. We should lect that to get the greatest amount of illumination from the expenditure of energy requires that we should subdivide our s; on the other hand, this increases the cost of installation, we must take both of these matters into account. In arranghe distribution of lights, we may, for private houses, whose igs do not vary much from 10 feet in height, make use of a ibution based on the number of square feet to be allowed to 6 *candle-power light.* The following tables will give an idea *lighting which may* be obtained from various distributi

PRIVATE HOUSES OF SMALL SIZE.

	Square feet.	No. 16 c. p. lights.	Min. ill'n if dark walls.	Ge e
Chambers..........	150	1	.25 c. ft.	I
"	200	2	.33 "	Fair
Kitchens..........	150	1	.25 "	Fair
Corridors..........		1		
Dining-room......	200	3	.50 "	G
Parlor..............	200	3	.50 "	G

or 1 16 candle-power light every 66 square feet with white walls.

FOR LARGER DWELLINGS.

	Square feet.	No. 16 c. p. lights.
Chambers..........	150	2
"	200	3
Kitchen..........		3
Pantry............		1
Dining room......	250	5
Library...	250	4-5
Parlor..............	250	4-5

or 1 16 candle-power light every 50 square feet; and if walls white make allowance by increasing the number of lights as per tab ing relative amounts of light reflected by different substances.

In these tables the height of lamps is taken at 7 feet 6 to 8 feet. For a greater height proper allowance must be as shown previously.

Hotels and Apartment-houses.—

The sleeping-rooms and parlors similar to private houses.

Corridors, 1st floor, bright, 1–3 lights chandelier every 25 feet, main
" " good, 1–2 " " subco
" other floors, " 1–2 " " main
" " fair, 1 " " subcor

Elevators, small, 1 light; large, 2 lights.

Café, 12 feet ceiling, brilliant, 1 16 candle-power light to every 2 feet, subdivided according to tables.

Dining-room, 15 feet high, 1 16 candle-power light to every 25 squ subdivided.

Office, reading-room, and bar similarly lighted.

Toilet-rooms, one to every two closets, set on partitions.

Bath-rooms 1 16 candle-power light to 50 square feet.

Barber-shop, like office, location front and behind chairs.

Theatres and Large Halls.—The height is so great that we e to take it into account, and it is better to work from cu. ft., ays understanding that lights are well distributed. .03 c. p. cu. ft. gives good illumination; .04 c. p. per cu. ft. gives bright mination. We should aim not to have light staring in the e, and therefore no chandeliers in centre; while lamps on galles should have opal globes whose absorption is about 50 cent.

Stores.—

ndescent light, 1 16 candle-power to 25–50 square feet.
light, 1 2000 candle-power every 15 feet or 225 square feet.
" 1 2000 candle-power every 30 feet if the store is narrow.

Markets.—

ps 15 feet high.
light, 1 2000 candle-power to every 40 feet or 1600 square feet.

CHAPTER XXXIV.

ELECTRIC MOTORS.

PRACTICALLY any direct-current dynamo, if current be supplied it, will operate as a motor, and a well-designed dynamo will ke a good motor. Certain alterations in winding and in er details are made in motors to improve certain qualities t may be specially desired. The motor will not necessarily in the same direction as it did as a dynamo when current ses through it in the same direction. For example, a series namo when operated as a motor will run in the opposite direcn from that which it had as a dynamo, and to make it turn in same direction it is necessary to reverse the direction of curt through the fields or armatures. A shunt machine used as a or will turn in the same direction that it had as a dynamo. versing the direction of current supplied to either, as by internging the connecting wires from positive to negative sides of line, will not change the direction of rotation of either series hunt motor. To reverse them it is necessary to reverse the direction of current running through the field or the armatu The compound dynamo, if the effect of the series coils is we relatively to those of the shunt coils, will behave like a sh motor. If the series coils preponderate in strength, it will act l a series motor.

Uses of Different Types.—The series motor is used wher is necessary to start with full load and where automatic regu tion for constant speed is not necessary, a hand regulation be used, as, for example, in hoists, cranes, street railways, etc.

A shunt motor is used where automatic regulation for const speed is desired. A good shunt motor will not change its sp more than 5 per cent. when the load is varied from zero to a m mum. While there is only one speed at which this autom regulation is closest, yet by putting resistances in series with armature a shunt motor can be made to run at slower speed still give fair regulation.

Compound motors are used where closer speed regulation t that given by shunt motors is desired, and in special cases, s as on planers where it is desired to check the sudden large flo current during reversal.

Regulation of Speed.—With a series motor, whose use is pr cally confined to constant potential circuits, there are two com methods of changing the speed:

1. To change the pressure supplied to it, by putting in s with the motor a rheostat in which more or less pressure is up according to the position of the rheostat-handle. Lowe the pressure will, of course, lower the speed.

2. To change the strength of the field of the motor. Th done by winding the field coils in sections and bringing ou ends to a sort of commutating device called a controller. In position of the controller handle the sections will all be in s cutting down the current and making the ampère turns o field, and hence its strength, low. In the next position, fo ample, three sections will be in series and three others in and the two sets of three in multiple, which will dimin

ance, let more current through, and increase the ampère . Another position will put more in multiple and less in , and so on till the final step puts all the sections in multiple, g the lowest possible resistance, highest number of ampères, est number of ampère turns, and strongest field. With the motor on constant potential circuits the speed is increased oportion as we increase the field strength. A combination e two methods is frequently used, the resistance being used g the first positions in order to cut down the excessive flow rrent on starting.

ith shunt motors it is necessary on starting to put a conside resistance in series with the armature, on account of its low resistance, which will vary from $\frac{1}{100}$ to $\frac{1}{1000}$ of an ohm s, according to its size. Such a low resistance thrown across olts would cause an enormous current, which would injure ommutator and brushes by sparking and the armature coils ating. As the machine speeds up the resistance may be cut , because the armature, which is turning in a magnetic field, ices an electro-motive force opposite to that of the circuit, ı tends to cut the current down. This electro-motive force led the *back* electro-motive force of the motor, and is always han the electro-motive force of the circuit by the amount red to drive current through the armature. It is, of course, rtional to the speed of the motor, and its relation to the o-motive force of the circuit is as follows: Let E be the ıre of the circuit at the motor terminals, R the resistance of mature, C the current flowing; then the back electro-motive $e = E - C\,R$. Starting resistances, or starting boxes as are called, are usually not designed to be left in circuit than the few seconds needed to get the motor up to speed; f made of wire large enough to carry the currents without eating, they can be used for regulating the speed of the . Such specially designed boxes are called *speed-regulating*, *ıply regulating, rheostats.*

ther method of varying the speed of a shunt motor is to a rheostat in the field circuit and vary the current flowing i the field. Weakening the field will speed up the machine, strengthening it will have the opposite effect. Note that just opposite to what happens with the series motor on co potential circuits.

Compound motors are generally regulated like shunt moto in some special cases the series coils are wound in sectio thrown in series, and finally in multiple, as is the case with motors.

Protective devices are specially necessary with shunt an pound motors on account of their very low armature resis as explained above; and all motors need to be protected fr danger of being overloaded. An overload, by slowing do motor, diminishes the back electro-motive force and th allows an excessive current to flow, which, if long cont would burn out the armature. The protection formerly us a pair of fuses, one in each of the circuit wires, which were c a size that they were expected to blow at any current exc that corresponding to the maximum load for which the was designed. Owing to the uncertain action of fuses, a c breaker is now almost universally used, mounted on the st box. Another thing which must be guarded against is this pose that the circuit to which the motor is connected is loaded, perhaps by some accident, and the circuit-brea that circuit on the switch-board should open. This would c current from the motor and it would stop. Now if nothin done except at the switch-board to throw in the circuit-b again, we should throw the full voltage on the motor arm none of the rheostat being in series with it, as it had bee viously cut out of the circuit when the motor was first b up to speed. The result, of course, would be a tremendou of current and injury to commutator, brushes, and perha armature, depending upon how quickly some one open switch which connected the motor to the circuit. To obvi [illegible] the rheostat arm has attached to it a sprin tends to pull it back to the position in which all of its coils are in series with the armature. At the other limit of its motion, where it would stand when all the coils had been cut out of the circuit, is a magnet wound with fine wire and supplied from the circuit wires. When the rheostat arm gets to this position the magnet holds it there by its attraction for a piece of iron mounted on the arm, as long as the current flows through the coil; but if the circuit-breaker goes off or the voltage disappears for any reason, the magnet lets go and the spring pulls the rheostat arm back to the position of safety.

Size and Speed of Motors.—Motors may be obtained of any desired size, voltage, and speed. The commercial sizes are from $\frac{1}{12}$, $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 3, 4, 5, 7½, 10, 15, 20, 25, 50, 75, 100 horse-power and upward. The standard voltages are 110, 220, and 500, these operating on voltages from 110 to 125, 220 to 250, and 500 to 550. As to speed, there is no such thing as standard speed for different sizes, the speeds of the different manufacturers varying widely. It should be understood that with motors, as with dynamos, the speed at which a certain size shall run determines the cost. For example, a machine of such size and winding that it will give 100 horse-power at a speed of 500 revolutions per minute, will give only 50 horse-power if the winding be altered so that it will run at half that speed.

A motor generator, as its name indicates, is a combined motor and generator. The most easily understood form would be a motor which might be designed for any voltage, speed, and power, coupled directly to the shaft of a dynamo designed for the same peed, but for any voltage and the same output as the motor. Such a machine has two distinct commutators, brushes, armaures, and fields. By using a common armature core and field, nd putting the two sets of armature windings on the same core, insulated, of course, carefully from each other, the compactness f the machine is very much improved, and this is the arrangement of *the modern direct*-current motor generator. Its principal *uses are as follows:*

1. To change from a high pressure and small current to a lower pressure and correspondingly greater current.

2. With its generator armature in series with some circuit to raise the pressure of that particular circuit higher than that of the other circuits supplied from the principal generator. In such uses it is called a booster.

3. In connection with storage batteries, it being used in series with the charging mains to increase the pressure in proportion as the batteries become more fully charged.

It is also used to a considerable extent in telephone exchanges for operating the calling circuits, the generator end being arranged to give an alternating current.

CHAPTER XXXV.

THE STORAGE BATTERY.

The principles of the storage battery have already been taken up in an earlier chapter, and it only remains to describe the battery as made and used in practice. Owing to the purchase by one company of all the important storage battery patents in this country the situation of the industry is much simplified, there being practically only one battery upon the market, which is known as the chloride battery. It derives its name from the method of making the plates, pencils of lead chloride being inserted in the leaden frames, to be afterward treated chemically so as to produce the active material of the plates. This treatment consists first in suspending the plate together with a zinc plate in a bath of zinc chloride, with the resulting formation of zinc chloride and pure lead, instead of the lead chloride. The zinc chloride dissolves away, leaving the pencils in the form of finely divided or spongy lead. The object of securing this spongy form of lead is to present as much surface as possible to the action of the liquid (sulphuric acid) to be used in the battery. These plates might be used as negative plates, although further treatment might

ove their action. To form positive plates two are taken and
nded in dilute sulphuric acid and a current sent through
. One of them becomes coated with a reddish-brown sub-
e, which is peroxide of lead. Hydrogen bubbles collecting
e surface of the other attack any oxide that may remain on
ther plate and leave a clean surface of lead. After the plates
been charged the charging current is shut off and they are
arged by connecting them together. They are then charged
, the oxidation of the first plate going to a greater depth
before. As this peroxide is the active material of the cell,

Negative Plate.

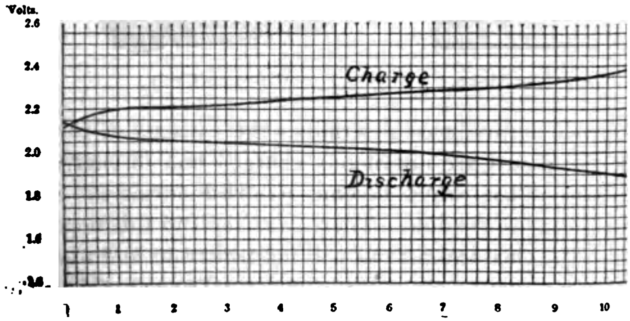
Storage Cell.

amount of it produced determines the capacity of the cell;
fore the plates are alternately charged and discharged, so
the layer of lead which becomes oxidized during the charge
be as deep as possible. There is a limit to this depth, be-
which the chemical actions will not penetrate, and when this
ached the forming process is stopped. The peroxide plate,
h is reddish in color, is the plate from which current flows
ng discharge, and is called the positive plate. The gray-
ed plate is the one toward which current flows during dis-
e, and is consequently called the negative plate. In making

up a storage cell from the previously formed plates we fi a negative plate, then a positive, then another negative, an there being always one more negative than positive plate the negatives are connected together by a lead strip, and si all the positives; but each negative is separated from neig positives by a space of perhaps an eighth of an inch, fill dilute sulphuric acid, the general arrangement being sl the cut.

Charge and Discharge.—After the completely formed and negative plates are put in the containing jar or ta dilute sulphuric acid and are electrically connected toget wire, current commences to flow and corresponding c changes occur. These changes are somewhat complex: a general way it may be said that the peroxide of lead positive plate is changed to lead sulphate and the pure lead of the negative plate is also changed to lead sulphat electro-motive force of the cell will during this process f about 2.2 volts when fully charged to 1.8 volts, at whi the discharge should be stopped, in order to prevent th being injured.

If current from some generator be sent through the cel

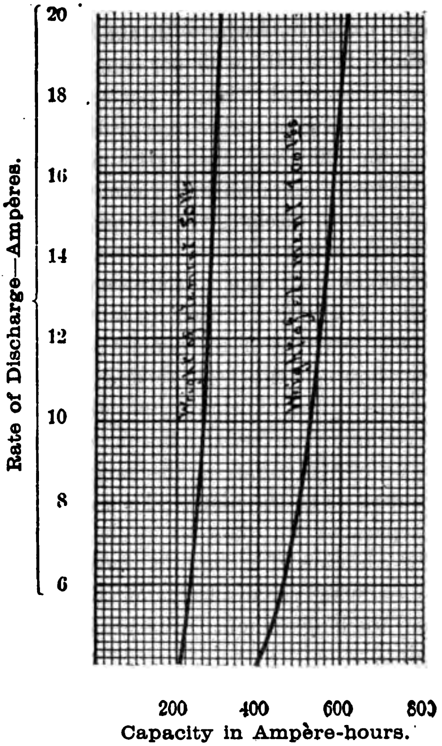


Charge and Discharge Curves.

on, sulphate of lead on the positive plate i
lead and the sulphate of lead on th

ate is changed to metallic lead, and with each charge and
rge of the cell these chemical actions take place. The
-motive force of the cell rises as the charge increases, and
riation can best be seen by plotting a curve, as in the ac-
nying diagram, which shows the variation of electro-motive
hrough a complete charge and discharge.

acity of Storage Cells.—The unit of capacity is the
-hour, and a cell of 50 ampère-hours' capacity is one



when *discharged at its* normal rate gives out such a number
ères for such a number of hours that the product of the num-

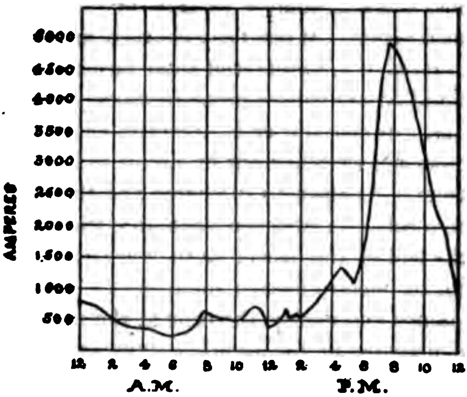
ber of ampères by the number of hours equals 50. · The capacity of a cell, or the number of ampère-hours which can be taken fro it without carrying the voltage lower than 1.8 volts, is very much affected by the rate of discharge, being much less at a rapi than at a slow rate of discharge. The accompanying diagra shows the variation of ampère-hour capacity of a cell when di charged at various rates.

Efficiency.—The efficiency of a cell is the ratio between th amount of power which can be taken out of it and that which i put into it. It, like capacity, varies with the rate of discharge, and may be anywhere from 50 to 95 per cent., according to th charge and discharge rates used. Eighty per cent. for the normal discharge-rate of a cell is a good value except for the very largest cells. To measure the efficiency the watt-hours put in during charge are measured by an ammeter and voltmeter, and similarly the watt-hours taken out in discharge. The quotient of the latter by the former is the efficiency.

The principal troubles of storage cells are *short-circuiting, buckling*, and *sulphating*. The first is caused by buckling of plates or by the dropping out of portions of the pencils of active material, which in time form between the positive and negative plates a connection which causes loss of charge and destruction of the plates if not noticed and remedied by taking out the material. Buckling is due to an excessive rate of discharge or an unequal discharge at different parts of the plate. To assist in preventing it the plates are separated by glass or rubber distance-pieces. Sulphating, or the production of a complex, hard, white-lead sulphate, is caused by carrying the discharge of the battery too far or by letting it stand too long without recharging. It is remedied by persistent charging.

Care of Cells.—In the care of cells the frequent use of a voltmeter and hydrometer is necessary. The voltmeter should be connected in succession to each cell of a battery, and the readings compared to see if they are uniform. If they are not, the cells g low readings need attention. The hydrometer tells the f the solution, which when fully charged should be 1.22. shes, as the cells are discharged, down to about 1.17. The of the hydrometer, therefore, give an indication of the ı of each cell in which it is placed. The regular use of o instruments, a careful attention to the discharge rate, nspection of cells, and the making good of water lost by ion, so as to keep the tops of the plates always covered, e the most vital points connected with the use of storage

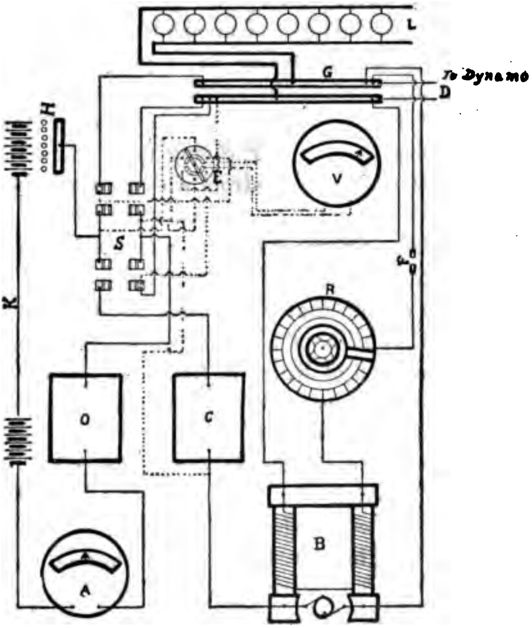
tages of Using Storage Batteries.—There are two cases the use of the storage battery is of the highest benefit.



; is to use it to take care of light loads, allowing the nachinery and perhaps the boilers to be shut down and ay with the expense of the necessary attendance for such y. The second is to take what is called the peak of the ı almost no electrical plant is the amount of power used In lighting work there is a variation something like vn in the diagram, where during the hours from four to s a very *large load.* The storage battery can be used to *vantage in supplying* power represented by the upper part of this curve, it being charged while the load on the is light, and thrown in multiple with the generators, so as to a part of the load, between the hours when the peak occurs. this way the boilers, engines, and dynamos work at a more uni load, and therefore more economically than they otherwise wo

Method of Connecting Batteries.—Owing to the fact that electro-motive force of a cell increases with charge and dimini with discharge, it is necessary to have special arrangements which a dynamo while supplying lights may charge a battery cells, and by which the electro-motive force of a set of cells be kept constant while they are supplying lamps. The arrang ment for discharge will be first described. Supposing a 110-v system, we must have a number of cells in series equal to volts, or about 60 cells. When fully charged, as each cell has electro-motive force of 2.2 volts, the total electro-motive force the 60 cells would be 132 volts, a pressure which would seriously injure the lamps. When the cells are fully charged, therefore, sufficient number are switched out of circuit to bring the press down to 110 volts. As the cells discharge and their electro-moti force falls, these cells are switched back into the circuit one at time, till at the end of the discharge they are all in circuit.

In charging, the electro-motive force rises. As it is desired run 110-volt lamps and charge the cells at the same time, we cannot raise the pressure of the lighting dynamo; so an auxiliary dynamo or booster is employed, its armature being put in seri with the cells and its field varied by its rheostat so as to gi enough additional volts for charging at the proper rate. The accompanying diagram of connections shows the arrangement. *B* i the booster and *R* its rheostat. *V* is a voltmeter and *A* an ammeter, so arranged that its needle stands in the centre of the sc when no current is flowing through it, moving to one side for charging current and to the opposite side for a discharge curr *K* represents the main battery and *H* the switch which throws th *reserve cells* in and out. S is a double-throw switch, which i *one position* connects the batteries to the lamps to be supp urrent, and in the other position connects it to the dynamo arging. *E* is a switch for connecting the voltmeter, so as to he voltage of the battery, the line, and the charging dynamo ooster respectively. *O* is an automatic circuit-breaker, which perate if too great current is taken out of the batteries, is a circuit-breaker which will open the circuit if the ing current becomes *less* than a certain value. This last is



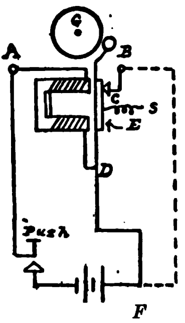
ary if a compound-wound dynamo is used in order to prohe dynamo from having a reverse current sent through it the battery if by accident it was slowed down or stopped the charging switch had been opened.

eral other arrangements are employed; but a proper undering of the one described above will be sufficient to enable gineer to comprehend the others without difficulty.

CHAPTER XXXVI.

ELECTRIC SIGNALS.

Nearly all signal systems coming under the charge of th nary engineer consist of four elements—the battery, the li operating station, and the receiving station. The batte nishes the electrical energy for operating the signals, and t serves to transmit this energy. The operating-station, whi erally consists of a key, a switch, or a push-button, clo electrical circuit and permits the operating-current to flow. receiving-stations are somewhat varied in design. They m sist of a bell or telegraph-sounder, giving the signals by so of a galvanometer or a shutter-drop, which conveys the by means of sight. Frequently the two methods of sour sight are combined. Of the four elements, the battery a have already been discussed in previous chapters, and the push-button is so simple that it requires no description than to say that it consists of a fixed contact-piece and m contact-piece, into each of which is connected one of the wires. When the two pieces are brought into contact th trical circuit is closed and current flows. receiving mechanisms will be taken up i nection with the special systems of sig of which they form a part.



Electric bell and circuit.

Electric Bells.—An electric bell c of an electro-magnet, to the armat which is connected a hammer arran strike a gong when the armature is pul to the core of the magnet by the passag electric current. When current ceas magnet loses its strength and a sprin the armature away from the core and a hammer from the gong. Bells are divid two classes, known as *single-stroke* and *vibrating* bells.

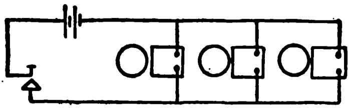
A single-stroke bell is one which makes one stroke only each ne that its push-button is pressed. In the accompanying cut, the line were connected as shown in solid lines, to A and D, the ll would be single stroke.

A vibrating bell is one whose hammer continues to vibrate as ng as its push-button is pressed. The way in which this is accomshed is simple. Suppose that in the cut on p. 758 above the conction between F and D is taken away and the connection between and B, shown with dotted line, is made instead. When the tton is pressed down, the circuit being closed, current will flow om F to B, B to the contact-point C, through the armature E to from D through the magnet coil to A, and from A back through e closed push and battery to F. Owing to the current, the ectro-magnet pulls the armature E toward itself and the hamer strikes the gong G; but as soon as the armature moves ward the magnet the circuit is opened, because C no longer aches E. The current therefore stops, and as the electro-magt no longer has any strength, the armature is pulled away from by the spring S. This movement, however, brings E and C to contact again, causing the whole action to be repeated, and is continues as long as the push-button is held down, provided e battery keeps up its strength. Such is the principle on which ork the ordinary bells used for houses, offices, etc.

The buzzer is practically a bell with the gong omitted, and is ed where the powerful noise of the bell would be annoying.

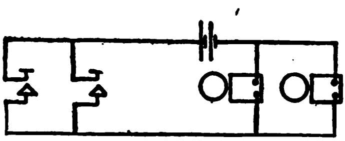
Styles of Bells.—Bells are known as *wooden box* if the workg parts are covered with wood, *iron box* if covered with iron, d skeleton frame if they are not covered at all.

Possible Arrangements of Bells.—The accompanying diagrams

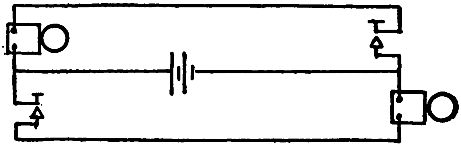


One push operating two or more bells at the same time.

ow *the method of connecting* in some of the more important cases.



Any one of two or more pushes operating one or more bells



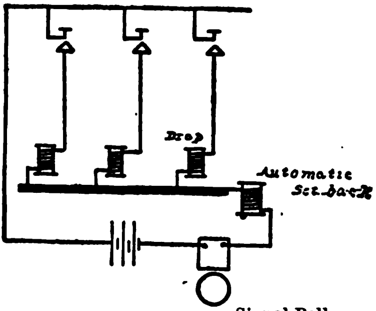
No. 1 push operating a distant bell at station No. 2, together w push at No. 2 operating a bell at No. 1, known as the return c

Any number of pushes may each operate its own bell or bu This system is the same as the annunciator system.

Any number of pushes may each operate its own bell and have a return call. This is the same as a return-call annunc system.

The annunciator in principle consists of a number of mounted together in a case, each operated by its own push lo in some distant place. In practice, however, it would be dif to tell from the sound of the bells which station was callin the hammers and gongs are omitted, and instead we ha simple mechanism operated by the armature, called the One of the simplest forms is shown in the cut on page When the current flows through the coil the armature drawn up a little way into the coil and the shutter *S*, whi hung eccentrically, being released when *A* is lifted, turns thr one-quarter turn. On the front side of the annunciator c needle, which is attached to the same pivot which carri moves from a horizontal into a vertical position. Each n being numbered or otherwise marked, the place from whic signal is sent is, of course, known. A rod carrying little serves when pushed up to restore the needles to their ho tion. This rod can be operated by hand or by an electro- ;net connected so as to be pulled up when any push is pressed. In this case all needles previously standing vertical assume the horizontal position, and then the needle corresponding to the button pressed turns into the vertical position. This arrangement is called the *automatic set-back.* The accompanying diagram shows the con-

Annunciator Drop.



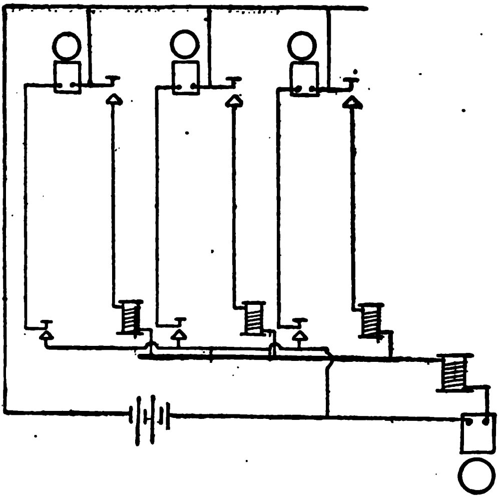
Annunciator System.

tions of an annunciator system. To attract attention the sig- bell is added, so connected that when any push is pressed it ;s.

'he return-call annunciator system, which is like the simple unciator system, with the addition of a wire between each push the annunciator, is shown in the diagram on page 762.

ire-alarm Attachment.—A device for closing simultaneously ain or all of the circuits ringing the distant bells as may be red, is frequently added for annunciators used in hotels and rtment-houses.

urglar-alarm systems are similar to simple annunciator sys- *with the addition* of a bell in an auxiliary circuit which is closed when any of the drops operate. This auxiliary bell therefore continue to ring till some one comes along and rest



Return-call Annunciator System.

the drops to their usual position with the needles horizontal. push-buttons are of a somewhat modified pattern and are pl in doors and window-casings, so that if either a door or wind opened the contacts of the button touch each other and clos circuit, causing the corresponding drop on the instrument to ate. Frequently the pushes of all the windows and outside of any one room are connected in multiple on one circuit, so any one of them when closed operates the drop correspondi not being necessary to have a drop for each window and doo only for each room.

Watchmen's systems for insuring that watchmen make rounds at the time and in the order in which they are expec do so, may be divided into two different classes, accordi the energy for actuating the recording device is derived

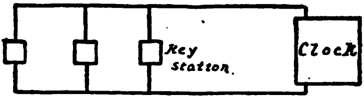
tery or a small dynamo, namely, into the *battery* and *magneto-*
tems. The battery system has two different types, the differ-
e consisting in the method of wiring and the design of push-
ton.

Battery System with Simple Push-button.—This system is
ed like a simple annunciator system. Its push-buttons are
such pattern that circuit will be closed in them only by push-
; into them a special key carried by the watchman. The an-
nciator of the ordinary system, with slight modification, becomes
watchman's clock. The signal bell and self-restoring magnet
the annunciator are omitted. The armature of each drop is
de to actuate a little needle which punctures a hole in a paper
ording-dial. This dial being divided in spaces corresponding
the hours from 12 o'clock to 12 o'clock, and being further sub-
ided into spaces corresponding to five minutes, and rotating so
to make one complete turn in the 12 hours, the position of the
nctured holes on the paper tells at what time they were made
the watchman. The dial has also a number of circles marked
it corresponding to the number of stations, and each needle
icks its holes in one of the circular spaces formed by these rings,
that a hole in a certain ring means that the key has been put
the corresponding station push-button. The weak point of this
stem is that if the watchman can get at the two wires leading to
y station and can connect them together, he can make the
ck register as if he had actually gone to that station.

The magneto-system overcomes this objection, and also obvi-
s the care of batteries. In this system the wiring and clock are
same; but instead of the special push-button to be operated by
ey, a little dynamo, called a magneto, is placed at each sta-
n. The watchman carries a handle which he puts on a stud
nected with the shaft of the dynamo armature. Turning the
ndle sends a current through the coil corresponding at the
ck and causes the needle to make a record.

***The other type of battery* system** has a less expensive system
viring than either of the two preceding, and it is very difficult

for the watchman to make a proper record on the clock without actually going to each station. At the clock one magnet and needle do all the recording for each watchman. Each push-button station is numbered, and on the dial when that station is operated the number of pricks are made in the paper corresponding to the station number. The station consists of an iron box with a hole in it for the watchman to insert his key. Inside the box is a sort of toothed wheel to which one of the wires is connected. The other wire is connected to a strip, which is adjusted so that the teeth will come in contact with it. As the watchman puts his key in he gives it a turn and the toothed wheel, having a number of teeth corresponding to the number of the station, is made to turn, and by its motion to make and break contact with the strip as many times as there are teeth. This will, of course, cause the needle to make an equal number of holes in the paper dial of the clock. The wiring system is of the simplest description, as will be seen from the diagram, the stations being in multiple across two wires. Its disadvantage, compared to the magneto-system, is that the batteries require some attention and expenditure for renewals. This is, however, slight, as half a dozen cells for each watchman suffice for ordinary conditions.



Batteries Required.—The type used is some form of the zinc-carbon sal-ammoniac battery. For single bells or annunciators with short circuits, as in a dwelling-house, three cells are usually sufficient. For larger buildings five or six will be needed. For automatic fire-alarms a much larger number is needed, the exact number being stated by the manufacturer, as a rule. For burglar-alarm and watch-clock systems six are as a rule sufficient, and sometimes a less number may be used.

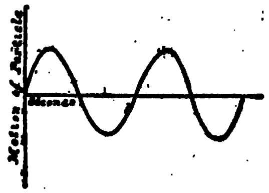
The wire used frequently is what is known to the trade as *annunciator* wire, the insulation of which consists of a double cotton *covering* dipped in paraffin. A better insulation, whose use ed, is what is known as office wire; while the *common* wire t is, the one in the sketches which runs to one side of all the s—should be made with weather-proof insulation. In the r class of work the *common* wire is made with a rubber insu- and the other wires of rubber or weather-proof.

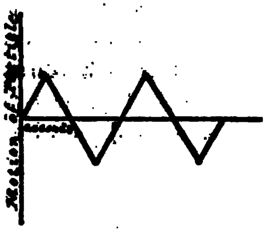
thods of Carrying Wires.—In the cheaper classes of work ires are tacked to wood-work with staples or held by a piece e folded around the wire and tacked to the wood. In fire- constructions, however, the wires are carried in conduit, should be of the iron-armored variety. The prevailing ice is to carry as many wires as is desired in one tube.

CHAPTER XXXVII.

THE TELEPHONE.

e phenomenon of sound is caused by vibrations of the par- of air; its pitch is dependent upon the *number* of vibrations cond, its loudness on the *wideness* of those vibrations, and its ty, that property by which we distinguish tones of the same and loudness, upon the *form* of the vibrations. This last point newhat difficult to understand. Suppose that a mass of air is vibration by a tuning-fork, and that we study the motion of le particle of air by plotting on a flat surface. Let distances right of the vertical represent time, and vertical distances sent the distance which the particle has moved through at any The motion of the particle would be represented by the line in the figure. Distances above the horizontal corre- to motion in one direction from its position of rest, and dis- s below the horizontal represent similarly motion in the op- direction. If we set the air into vibration by means of a d violin-*string, the shape* of the wavy line would be very much *d, as in the second figure.* To perfectly reproduce sounds it is necessary to reproduce the pitch or number of waves per and the quality or form of these waves, and sufficient wide

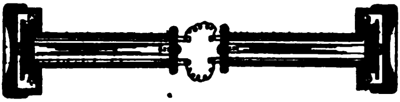




vibration (distance above and below the horizontal line) t the listening ear.

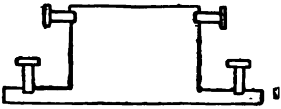
The telephonic transmission of speech between two may be best considered in two parts: 1. The transmitter, produces in the wires connecting the two points a varying whose curve of variation, if plotted, has the same num vibrations per second, and whose form is the same as that sound waves which strike upon the diaphragm of the tran mouthpiece. 2. The receiver, into which comes this varyi rent, which is made to set a diaphragm into vibrations similar to those of the transmitter diaphragm. The recei phragm, of course, sets the air surrounding it into vibratio lar to those caused by the voice speaking, and the ear listener is affected in the same way, though not so strongl the speaker were talking directly to him. In the early tele the transmitters and receivers were identical, but in recent another type of transmitter has been developed to secure loudness. The receiver is, however, still used in nearly it nal form, and is known as the *magneto-receiver.*

The magneto-receiver consists of a bar magnet with cylindrical pole-piece of soft iron on one end. Mounted *pole-piece* as an axis is a little wooden spool wound with fin *In front of* the spool is a thin circular disk of soft ir gram shows two of these connected by wire ready for talking. pose the left-hand one is used as the transmitter and the other

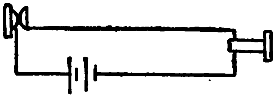


Magneto-receivers used Alternately as Transmitters.

he receiver, the action is as follows: The voice of the speaker the diaphragm of the transmitter into vibration. The motion the iron near the magnet-pole alters the position and density the magnetic lines of force enclosed by the coil and sets up a ying electro-motive force in the coil. This produces a current the line with a similar variation or wave-form to the original nd-wave. This varying current flowing around the coil of the *eiver* causes the strength of its pull on the receiver diaphragm vary in a similar way, and therefore to set up in the receiver phragm vibrations similar to those of the transmitter diaragm. This sets the surrounding air into similar vibration. is causes the listener's ear to be affected just as if the speaker re talking directly in his ear, although not so loudly. When speaker has finished he puts the trument to his ear and listens to other party. To avoid the nesity of changing, each party may ve two telephones, one for talking d the other for listening, connected in series as shown in the gram.

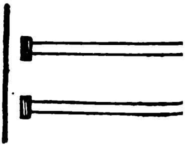


The Battery Transmitter.—In the magneto-transmitter just deibed the varying current is produced by setting up an electrotive force whose wave-form of variation is similar to that of sound-wave producing it. Another way to produce the varycurrent *is to use a constant* electro-motive force, but employa *resistance varied by the* sound-wave and having the same wave-form of variation. It was discovered that the resistanc the point of contact of two pieces of carbon varied exactly the pressure put upon it, or rather inversely as the pressure upon it, the conductivity varying exactly with the pressure. virtue of this discovery the use of the battery transmitter bec possible. A current is sent thr the circuit consisting of the rece line, and carbon contact, as sh in the diagram. One of the ca pieces is fixed and the other m with the diaphragm. When latter is spoken against, its vibrations cause the varying press on the contact between the two carbon pieces. This causes varying resistance, which produces the varying current neces to transmit speech.



Carbon Transmitter.

Improved Forms of Receiver.—In the later forms the rece magnet is made of a horseshoe shape, each pole having a spool of wire, it having been found experimentally that with this form a given motion of the diaphragm produces the greatest possible change in the number of lines of force enclosed by the coils.

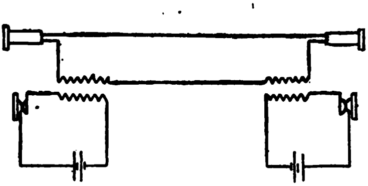


Horseshoe Magn Receiver.

Improved Forms of Transmitters.—In order to make the v ation of resistance as great as possible the number of contac increased by having the circuit pass through a number of s carbon particles against which the diaphragm presses. The signs of such transmitters are exceedingly numerous, the p cipal difficulties to be overcome being questions of patents the liability of the carbon particles to pack, which prevents t freedom of movement.

The Induction Coil.—On long lines the resistance of the li which is fixed in value, is so much greater than that of the v able carbon contacts that the effect of the latter is practic To overcome this difficulty the induction-coil is use

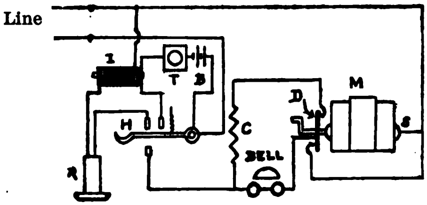
sists of a bundle of fine iron wires about three inches long,
l wound around these as an axis is a coarse wire coil of about
16 wire and a fine wire
of No. 24 or smaller, ac-
ding to the length of line.
e coil is connected as shown
he diagram, and the effect
so much improved that
ech is possible, commer-
lly, over distances as great
1500 miles. There is no trouble in speaking over greater dis-
ces than this were it not for the expense of constructing suit-
e lines.



Connections using Induction Coils.

Methods of Calling Up.—For short lines a return-call bell
tem is employed, but for distances over two or three hun-
d feet either specially wound bells or a *magneto-call* must
used.

The magneto-call consists of a small hand dynamo, which gives
rnating currents. These traverse the coils of an electro-mag-
whose armature is a permanent magnet, and alternately tip it
way or the other. The armature carries a hammer, which



Connections of a Magneto-call Instrument.

kes alternately two gongs placed one on each side of it. The
thod of connecting a telephone instrument with a magneto-
is shown in the diagram, where the letters indicate the follow-
parts:

M, the magneto-generator.

R, the receiver, to be hung up on a hook, except when talking

H, the automatic hook.

T, the transmitter.

I, the induction-coil.

B, the battery.

C, a shunt coil in multiple with bell when magneto is bein turned.

D, contact disk to which one end of magneto-armature is co nected.

S, end of armature shaft to which other end of armature co is connected.

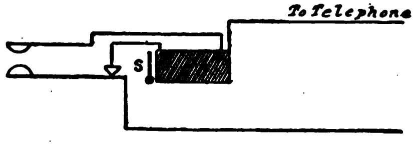
The diagram shows the condition of things when no one i talking. With no one talking the call-bell only is in circuit wi the line wires. When the operator at this instrument wants t call up No. 2 he turns the handle of the magneto. This push over the armature a little to the right and closes the contact at *D*, breaking contact at the hook-shaped contact opposite *D* on the disk, and throws his generator on to the line, so that it rings his bell and that of No. 2. When both receivers are taken off the hook the bells and magnetos are cut out of circuit and the induction-coil, receiver, and battery are thrown into connection, as will be seen from the diagram.

Telephone Systems.—There are two systems under which telephones are operated, known as the *intercommunicating* system and the *exchange* system.

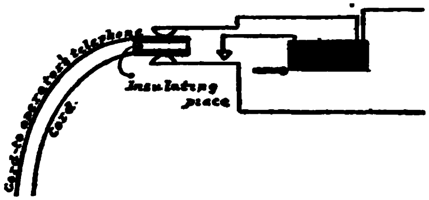
The intercommunicating system consists of instruments as above described, combined with a suitable number of wires running to all instruments, and at each instrument such a form of mechanical-contact changing switch as to enable each telephone station to call up any particular station without interfering with any others who may be talking. There are numerous examples of such systems, only a few of which are satisfactory. All of them require as many wires running to all telephones as there are tele in the system, plus two wires in addition, while some of ems require three wires. They may be operated with a or magneto-call, though usually using the former. The uirement which they should fulfil is that after finishing tion it shall only be necessary to hang up the receiver. stems require also that a switch-handle shall be returned me place or that a plug shall be put in a certain hole, t station cannot be called up by others. Such an arnt, however, is fatally defective. For numbers above fifwenty it is rarely desirable to use the intercommunicating although much larger systems are in operation.

nge System.—In such systems two (or sometimes three) n from each telephone to a central point, at which an sits, whose duty it is to connect the lines of any two tele-y means of a convenient switch-board and to disconnect en they have finished talking. The connections are made a pair of flexible cords, called talking cords, which are to plug-shaped pieces. The signals of the person calling made on an ordinary annunciator if a battery call is used; n general a magneto-call is employed, a special form of used.

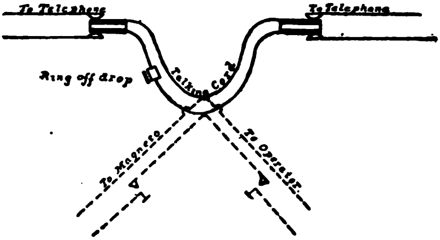
drop is made in many different forms, one of which is ed in the cut. The shutter S has on its face a number nding to the num-e telephone whose ad into it and is in such a way n a current passes the coil of the drop attached to the armature of the coil is moved out of the way shutter falls, calling the attention of the operator to that ar subscriber. The operator puts one of a pair of talking connection with the calling telephone, as shown in the cut. The plug when pushed into the drop separates the ct-pieces and one wire of the cord is connected to one si



of the line and the other wire of the cord to the other side o line. It will also be noticed that the coil is cut out of circuit b



spreading action of the plug. The operator asks what num wanted, and on receiving a reply puts the plug on the othe of the cord into the drop of the number wanted and presses or throws a switch, which for a moment disconnects the cord the caller's line. Then she connects a magneto-call to the ta cord and rings up the party desired. Then releasing the l switch she throws the two subscribers into connection with



other, as shown in the diagram in solid line. The dotted line how the operator's telephone or magneto may be thrown in by ing the proper keys. When the two parties have finished t each hangs up his receiver and gives a partial turn to the l of his magneto. This will make the shutter of the ring-of ***fall*** and tell the operator that that particular talking-cord ***longer*** in use. She then takes out the plugs and restores the off drop shutter and the shutters of the other two drops ertical positions, ready to receive new signals. There are, of urse, several talking-cords, so that any number of pairs of subribers may talk together without interfering with each other.

In large exchanges numerous additions and modifications to ch an arrangement are made in order to make the operation of e board quicker and less liable to error. For example, the fallg of a shutter is made to close an auxiliary circuit and ring a ell or light a lamp to call the operator's attention, and a power enerator is used so that simply pressing a key tends to send a nging current on to the line to which the talking-cord is conected, etc.

QUESTIONS.

How may an electric current be produced?

What is a battery?

What metal is usually employed for one pole of a battery?

What kind of a solution is generally employed?

What are some of the effects which an electric current will roduce.

What is an *anode?* A *cathode?*

How can the direction in which an electric current flows be etermined?

What is a galvanometer, and how is it made?

What are lines of magnetic force? How may they be oberved?

What is produced when lines of force are cut or crossed by a onductor?

What is Fleming's rule for the direction of induced currents?

What is an electro-magnet?

What is the fundamental experiment on which the electric motor is based?

Explain how the idea of electrical resistance has arisen?

What does e. m. f. mean?

What *are the three princi*pal electrical units, and what are their *ames?*

What is a kilowatt?

What are the laws governing resistance?

What is conductivity?

Define specific resistance.

What effect does a change in temperature have on resistance?

For what purpose is an insulator used?

What is the relation of heating effect to current strength?

Define electro-chemical equivalent.

How much silver will be deposited in one second by a curre of one ampère?

Describe the general process of electro-plating.

How may an electro-motive force be produced?

Give an example of some values used in practice.

What is Ohm's law?

Describe the method of measuring a current.

How would you measure voltage? How a low resistance?

How would you measure a high resistance?

Describe the measurement of power.

What is the principle on which the Edison meter operates?

What is a storage battery?

What is an open-circuit battery? Describe one.

Describe the Daniell cell. The Edison-Lalande. For wh kinds of work is each of these cells suited?

When would you use a bichromate cell?

How would you amalgamate a zinc plate?

By analogy how may a dynamo be regarded?

Describe an ideal simple dynamo with commutator.

What is the difference between a ring and a drum armature?

Why are armatures slotted? Why laminated?

What is a multipolar dynamo, and why is it made?

What is a series dynamo? A shunt dynamo? A compound

What is a characteristic? Draw the characteristics of th three types mentioned.

What is meant by over-compounding, and why is it done?

e regulation of a shunt machine accomplished?

What is a switchboard, and for what is it used?

Describe the ground detector.

Explain the purpose and action of a circuit-breaker.

Explain how to run two dynamos in multiple.

Describe the series system of distribution. State disadvantages.

Describe the parallel system and state its advantages.

What are *feeders?* *Mains?* *Branches?*

Describe the Edison three-wire system. What advantage has it?

Explain how to calculate the size of wire for a given distance, urrent, and drop.

Why are high electric pressures used?

Explain the methods used in insulating conductors.

Describe the various methods used in carrying electrical con-uctors.

What is a fuse, and what is its purpose? What is a cut-out?

Describe the various kinds of switches.

What is a socket? A receptacle? Describe the Chapman.

Why are insulating joints used?

What is a dimmer?

What is a 2000-c. p. arc lamp?

What must all satisfactory lamps do?

What is an enclosed arc, and what are its advantages?

Describe the incandescent lamp and its manufacture.

What candle-powers and voltages are commonly made?

What is meant by the efficiency of a lamp?

How does it vary with the life?

When is it desirable to use a high efficiency lamp?

What is the unit of illumination, the candle-foot?

How does intensity of illumination vary with the distance?

What is the effect of color on the amount of light reflected?

Show the advantage of scattered lights over the same number massed at one point.

What difference exists between a dynamo and a motor?

For what purpose is a series motor used?

*When is a shunt mot*or desirable?

How is speed regulation obtained with a series motor? How with a shunt motor?

Explain why a starting-box is needed for motors on constant potential circuits.

Explain what protective devices are needed.

What is a motor-generator? What are its principal uses?

Describe the *chloride* accumulator or storage battery.

How can you tell which plates are positive and which negative?

Describe the phenomena of charge and discharge and show the variation of pressure at the cell terminals.

What is an ampère-hour?

How does the rate of discharge affect the efficiency and capacity of a storage cell?

What are the principal troubles of storage cells? State the advantages of using them.

Describe an electric bell, both single-stroke and vibrating.

What is a buzzer?

Describe an annunciator system. How does the return-call system differ?

Explain the operation of a fire-alarm attachment.

What modifications are made for a burglar-alarm system?

Explain a watchman's time-detector system?

What are the advantages of the magneto system?

What batteries would you use for an annunciator system? What kinds of wire are used, and how carried?

How is sound produced? What are its three qualities?

What is necessary in order to reproduce a certain sound?

Explain the magneto receiver.

Explain the telephone transmission of speech by means of it.

Describe the battery transmitter.

What improvements have been made in receivers? What in transmitters?

What is an induction coil, and for what purpose is it used?

Explain the magneto-call system.

What is in an intercommunicating telephone system?

PART X.

ES AND TABLES USED IN CALCULATION.

CHAPTER XXXVIII.

hmetic is the art of computation with numbers or known ties. It comprises various operations, such as addition, subn, multiplication, division, powers, roots, ratio, proportion,

Signification of Signs Used in Calculations.

:	signifies	Equality,	as 3 added to 2 = 5.
	"	Addition,	" $4 + 2 = 6$.
	"	Subtraction,	" $7 - 4 = 3$.
	"	Multiplication,	" $6 \times 2 = 12$.
	"	Division,	" $16 \div 4 = 4$.
: : :	"	Proportion,	" 2 is to 3 so is 4 to 6.
	"	Square Root,	" $\sqrt{16} = 4$.
	"	Cube Root,	" $\sqrt[3]{64} = 4$.
	"	3 is to be squared,	" $3^2 = 9$.
	"	3 is to be cubed,	" $3^3 = 27$.

$+ 5)\ 4 = 28$ signifies that if two and five are added together and their sum multiplied by four the product equals twenty-eight.

s assumed that the user of this book is familiar with the simpler ns, such as addition, subtraction, multiplication, etc., and hence e not taken up. The rules given in this chapter are intended only h the memory. *Those who* desire a thorough treatment of the sub-*referred to Greenleaf's* Arithmetic.

+, plus, means that the number after it is to be *added* t number before it; thus, 5 + 4 are 9.

—, minus, means that the number after it is to be *subtr* from the number before it; thus, 5 — 4 is 1.

×, multiplied by, means that the number before it is to be *tiplied* by the number after it; thus, 9 × 3 are 27.

÷, divided by, means that the number before it is to be *di* by the number after it; thus, 9 ÷ 3 are 3.

=, equal to, means that the quantity after it is of the value as the quantity before it; thus, 5 + 6 = 11.

There are two systems of notation used in arithmetic, the A and the *Roman*. The former is the familiar one, based o figures

1, 2, 3, 4, 5, 6, 7, 8, 9, 0,

any two or more of which joined together make a number. Roman is no longer used in calculations but is frequentl ployed in numbering. One of the principal defects of thi tem is that it has no symbol for the cipher.

ROMAN NOTATION.

The following ten characters represent in Roman notatio numbers from one to ten, viz.:

I, II, III, IV, V, VI, VII, VIII, IX, X.

Larger numbers are made up by combining these signs Eleven, XI; twelve, XII; thirteen, XIII; twenty-one, XX The table of Arabic and Roman equivalents will make this

Arabic.	Roman.	Arabic.	Roman.	Arabic.	Roman.
13	XIII	20	XX	70	LXX
14	XIV	21	XXI	80	LXX
15	XV	30	XXX	90	XC
16	XVI	40	XL	91	XCI
17	XVII	50	L	100	C
18	XVIII	60	LX	101	CI
19	XIX	61	LXI	102	CII

Ratio.

Ratio is the relation as to magnitude which one number bears another, thus

$$6:3$$

read 6 is to 3, and means the numerical relation which 6 bears 3. The ratio of two quantities is measured by the quotient obined in dividing the one by the other. For this reason it may so be written in the form of a fraction thus:

$$6:3=\tfrac{6}{3}=2;$$

at is, the ratio of 6 to 3 is equal to 6 divided by 3, which equals 2.

Proportion.

Proportion is an expression of equality between two ratios, thus

$$6:3=4:2$$

a proportion, which may also be written

$$6:3::4:2$$

$$\tfrac{6}{3}=\tfrac{4}{2}$$

It will be observed that every proportion must consist of four rms, of which the two outer ones are called the *extremes* and the vo inner ones the *means*. Thus in the above proportion 6 and 2 re the extremes, while 3 and 4 are the means. In every true roportion the product of the means must be equal to the prodct of the extremes; hence if three terms of a proportion are nown, the fourth may be found by the

RULE OF THREE.

If two means and one extreme are given, divide the product of e means by the extreme; the quotient will be the other exeme, and *vice versâ*, thus:

$$8:4::\ ?\ :12.$$

To find the other mean, we multiply 8 by 12 and divide by 4.

$$\frac{8 \times 12}{4} = 24,$$

which is the other mean.

Example.—If it requires a 25 horse-power engine to run thr tools of a certain kind, how many horse-power will be required t run 24 tools of the same kind?

$$3 : 24 : : 25 : ?$$

$$\frac{24 \times 25}{3} = 200 \text{ horse-power.}$$

Instead of using an interrogation point to represent the u known term, it is customary to use the letter x.

FRACTIONS.

To reduce from common or vulgar fractions to decimal fra tions, annex ciphers to the numerator and divide by the deno nator. Thus $\frac{1}{16} = 1 \div 16 = .0625$.

TABLE OF VULGAR AND DECIMAL FRACTIONS OF AN INCH.

Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.	Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.	Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.
$\frac{1}{32}$	·03125	$\frac{3}{8}$	·375	$\frac{11}{16}$	·6875
$\frac{1}{16}$	·0625	$\frac{3}{8}\ \frac{1}{32}$	·40625	$\frac{11}{16}\ \frac{1}{32}$	·71875
$\frac{1}{16}\ \frac{1}{32}$	·09375	$\frac{7}{16}$	·4375	$\frac{3}{4}$	·75
$\frac{1}{8}$	·125	$\frac{7}{16}\ \frac{1}{32}$	·46875	$\frac{3}{4}\ \frac{1}{32}$	·78125
$\frac{1}{8}\ \frac{1}{32}$	·15625	$\frac{1}{2}$	·5	$\frac{13}{16}$	·8125
$\frac{3}{16}$	·1875	$\frac{1}{2}\ \frac{1}{32}$	·53125	$\frac{13}{16}\ \frac{1}{32}$	·84375
$\frac{3}{16}\ \frac{1}{32}$	·21875	$\frac{9}{16}$	·5625	$\frac{7}{8}$	·875
$\frac{1}{4}$	·25	$\frac{9}{16}\ \frac{1}{32}$	·59375	$\frac{7}{8}\ \frac{1}{32}$	·90625
$\frac{1}{4}\ \frac{1}{32}$	·28125	$\frac{5}{8}$	·625	$\frac{15}{16}$	·9375
$\frac{5}{16}$	·3125	$\frac{5}{8}\ \frac{1}{32}$	·65625	$\frac{15}{16}\ \frac{1}{32}$	·96875
$\frac{5}{16}\ \frac{1}{32}$	·34375				

e first column $\frac{1}{16}\ \frac{1}{32}$ means $\frac{1}{16} + \frac{1}{32}$; $\frac{1}{8}\ \frac{1}{32}$ means $\frac{1}{8} +$

Powers.

The power of a number indicates how many times the number to be multiplied by itself. Thus, 2 to the fourth power means multiplied by itself four times.

$$2 \times 2 \times 2 \times 2 = 16.$$

It is usually written with a small numeral at the top, thus:

3^2, means three to the second power or 3 squared.
3^3, " " third " or 3 cubed.
3^4, " " fourth " etc.

Example.—What is the fifth power of 3?

$$3 \times 3 \times 3 \times 3 \times 3 = 243.$$

Roots.

A root is the reverse of a power; thus the third or cube root of 7 means the number which, multipled by itself three times, ould give a product of 27. Roots are usually written with the umber of which a root is to be extracted under the radical sign $\surd$, with a small numeral indicating which root, thus

$$\sqrt[3]{1728}$$

eans the cube or third root of 1728. If no numeral is placed in he radical, the second or square root is meant.

The square root may be extracted by the following:

Rule.—Separate the given number into as many periods as posible, beginning at the right by placing a mark between the second nd third digits, the fourth and fifth, the sixth and seventh, etc. If he number contains a decimal, begin at the decimal point instead f at the right, and separate as before, going toward the left for he whole number and toward the right for the decimal.

Find the greatest square contained in the left-hand period, write he root of it at the right of the number, and subtract the square rom the left-hand period.

Bring down the next period to the right of the remainder for a ew *dividend and double* the root already found for a trial divi-r. *Find how often this* divisor is contained in the dividend exclusive of the right-hand figure, and write the quotient as the figure of the root.

Annex the last root figure to the trial divisor for the divisor, which multiply by the last root figure and subtract product from the dividend. To the remainder bring down next period for a new dividend.

Continue the operation until all of the periods have been bro down.

NOTE.—If a dividend does not contain its corresponding divisor, a c must be placed in the root and also at the right of the trial divisor; bring down the next period and proceed as before. When there is mainder at the end the decimal may be continued by adding ciphers.

Example.—

$\sqrt{15141.3025}$?

```
        1'51'41.30'25|123.05—Ans.
        1
      22|51
        |44
     243|741
        |729
   24605|123025
        |123025
```

The cube or third root of a number may be extracted b following

Rule.—Separate the number into periods the same as in s root, except that each period contains three instead of two d

Find the greatest cube in the first period, and write its ro the first figure in the required root. From that period sub the cube, and to the remainder bring down the next perio a dividend.

Multiply the square of the root figure by three hundred trial divisor, and see how often it is contained in the dividend ite the result as the next figure of the root.

the trial divisor thirty times the product obtain

ltiplying the root, excepting the units figure, by the units fig-
e and add the square of the last figure for a true divisor.
Multiply the true divisor by the last figure of the root, subtract
product from the dividend and to the remainder bring down
next period for a new dividend.
Multiply the square of the root figures already found by three
ndred for a new trial divisor and proceed as before until all the
riods are brought down.

Note.—What has been said in the note after the rule for extracting square
t applies also to cube root, except that two ciphers must be placed at the
ht of a true divisor, instead of one, when it is not contained in the cor-
ponding dividend.

Example.—

$$\sqrt[3]{122615.327232}\,?$$

$$\begin{array}{rr|l}
 & 122'615.327'232 & \underline{49.68} \\
 & \underline{64} & \\
100 \times 3 \times 4^2 = & 4800 & 58615 \\
30 \times 4 \times 9 = & 1080 & \\
9^2 = & \underline{81} & 53649 \\
 & 5961 & \\
300 \times \overline{49}^2 = & 720300 & 4966327 \\
30 \times 49 \times 6 = & 8820 & \\
6^2 = & \underline{36} & \\
 & 729156 & 4374936 \\
300 \times \overline{496}^2 = & 73804800 & 591391232 \\
30 \times 496 \times 8 = & 119040 & \\
8^2 = & \underline{64} & \\
 & 73923904 & 591391232
\end{array}$$

The raising of powers and extraction of roots of numbers may
performed by the aid of *logarithms* much more easily than by
mmon rules given above. An explanation of the use of loga-
thms will be found further on in this chapter, and the student
ill be well repaid for the labor required to master them by the
which he will derive from their employment.

TABLE

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS OF ALL NUMBERS FROM 1 TO 620.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1.	1.
2	4	8	1.4142 136	1.2599 21
3	9	27	1.7230 508	1.4422 496
4	16	64	2.	1.5874 011
5	25	125	2.2360 68	1.7099 759
6	36	216	2.4494 897	1.8171 206
7	49	343	2.6457 513	1.9129 312
8	64	512	2.8284 271	2.
9	81	729	3.	2.0800 837
10	1 00	1 000	3.1622 777	2.1544 347
11	1 21	1 331	3.3166 248	2.2239 801
12	1 44	1 728	3.4641 016	2.2894 286
13	1 69	2 197	3.6055 513	2.3513 347
14	1 96	2 744	3.7416 574	2.4101 422
15	2 25	3 375	3.8729 833	2.4662 121
16	2 56	4 096	4.	2.5198 421
17	2 89	4 913	4.1231 056	2.5712 816
18	3 24	5 832	4.2426 407	2.6207 414
19	3 61	6 859	4.3585 989	2.6684 016
20	4 00	8 000	4.4721 36	2.7144 177
21	4 41	9 261	4.5825 757	2.7589 243
22	4 84	10 648	4.6904 158	2.8020 393
23	5 29	12 167	4.7958 315	2.8438 67
24	5 76	13 824	4.8989 795	2.8844 991
25	6 25	15 625	5.	2.9240 177
26	6 76	17 576	5.0990 195	2.9224 96
27	7 29	19 683	5.1961 524	3.
28	7 84	21 952	5.2915 026	3.0365 889
29	8 41	24 389	5.3851 648	3.0723 168
30	9 00	27 000	5.4772 256	3.1072 325
31	9 61	29 791	5.5677 644	3.1413 806
32	10 24	32 768	5.6568 542	3.1748 021
33	10 89	35 937	5.7445 626	3.2075 343
34	11 56	39 304	5.8309 519	3.2396 118
35	12 25	42 875	5.9160 798	3.2710 663
36	12 96	46 656	6.	3.3019 272
37	13 69	50 653	6.0827 625	3.3322 218
38	14 44	54 872	6.1644 14	3.3619 754
39	15 21	59 319	6.2449 98	3.3912 114
40	16 00	64 000	6.3245 553	3.4199 519
	16 81	68 921	6.4031 242	3.4482 172

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
42	17 64	74 088	6.4807 407	3.4760 266
43	18 49	79 507	6.5574 385	3.5033 981
44	19 36	85 184	6.6332 496	3.5303 483
45	20 25	91 125	6.7082 039	3.5568 933
46	21 16	97 336	6.7823 3	3.5830 479
47	22 09	103 823	6.8556 546	3.6088 261
48	23 04	110 592	6.9282 032	3.6342 411
49	24 01	117 649	7.	3.6593 057
50	25 00	125 000	7.0710 678	3.6840 314
51	26 01	132 651	7.1414 284	3.7084 298
52	27 04	140 608	7.2111 026	3.7325 111
53	28 09	148 877	7.2801 099	3.7562 858
54	29 16	157 464	7.3484 692	3.7797 631
55	30 25	166 375	7.4161 985	3.8029 525
56	31 36	175 616	7.4833 148	3.8258 624
57	32 49	185 193	7.5498 344	3.8485 011
58	33 64	195 112	7.6157 731	3.8708 766
59	34 81	205 379	7.6811 457	3.8929 965
60	36 00	216 000	7.7459 667	3.9148 676
61	37 21	226 981	7.8102 497	3.9364 972
62	38 44	238 328	7.8740 079	3.9578 915
63	39 69	250 047	7.9372 539	3.9790 571
64	40 96	262 144	8.	4.
65	42 25	274 625	8.0622 577	4.0207 256
66	43 56	287 496	8.1240 384	4.0412 401
67	44 89	300 763	8.1853 528	4.0615 48
68	46 24	314 432	8.2462 113	4.0816 551
69	47 61	328 509	8.3066 239	4.1015 661
70	49 00	343 000	8.3666 003	4.1212 853
71	50 41	357 911	8.4261 498	4.1408 178
72	51 84	373 248	8.4852 814	4.1601 676
73	53 29	389 017	8.5440 037	4.1793 39
74	54 76	405 224	8.6023 253	4.1983 364
75	56 25	421 875	8.6602 54	4.2171 633
76	57 76	438 976	8.7177 979	4.2358 236
77	59 29	456 533	8.7749 644	4.2543 21
78	60 84	474 552	8.8317 609	4.2726 586
79	62 41	493 039	8.8881 944	4.2908 404
80	64 00	512 000	8.9442 719	4.3088 695
81	65 61	531 441	9.	4.3267 487
82	67 24	551 368	9.0553 851	4.3444 815
83	68 89	571 787	9.1104 336	4.3620 707

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
84	70 56	592 704	9.1651 514	4.3795 191
85	72 25	614 125	9.2195 445	4.3968 296
86	73 96	636 056	9.2736 185	4.4140 049
87	75 69	658 503	9.3273 791	4.4310 476
88	77 44	681 472	9.3808 315	4.4479 602
89	79 21	704 969	9.4339 811	4.4647 451
90	81 00	729 000	9.4868 33	4.4814 047
91	82 81	753 571	9.5393 92	4.4979 414
92	84 64	778 688	9.5916 63	4.5143 574
93	86 49	804 357	9.6436 508	4.5306 549
94	88 36	830 584	9.6953 597	4.5468 359
95	90 25	857 375	9.7467 943	4.5629 026
96	92 16	884 736	9.7979 59	4.5788 57
97	94 09	912 673	9.8488 578	4.5947 009
98	96 04	941 192	9.8994 949	4.6104 363
99	98 01	970 299	9.9498 744	4.6260 65
100	1 00 00	1 000 000	10.	4.6415 888
101	1 02 01	1 030 301	10.0498 756	4.6570 095
102	1 04 04	1 061 208	10.0995 049	4.6723 287
103	1 06 09	1 092 727	10.1488 916	4.6875 482
104	1 08 16	1 124 864	10.1980 39	4.7026 694
105	1 10 25	1 157 625	10.2469 508	4.7176 94
106	1 12 36	1 191 016	10.2956 301	4.7326 235
107	1 14 49	1 225 043	10.3440 804	4.7474 594
108	1 16 64	1 259 712	10.3923 048	4.7622 032
109	1 18 81	1 295 029	10.4403 065	4.7768 562
110	1 21 00	1 331 000	10.4880 885	4.7914 199
111	1 23 21	1 367 631	10.5356 538	4.8058 995
112	1 25 44	1 404 928	10.5830 052	4.8202 845
113	1 27 69	1 442 897	10.6301 458	4.8345 881
114	1 29 96	1 481 544	10.6770 783	4.8488 076
115	1 32 25	1 520 875	10.7238 053	4.8629 442
116	1 34 56	1 560 896	10.7703 296	4.8769 99
117	1 36 89	1 601 613	10.8166 538	4.8909 732
118	1 39 24	1 643 032	10.8627 805	4.9048 681
119	1 41 61	1 685 159	10.9087 121	4.9186 847
120	1 44 00	1 728 000	10.9544 512	4.9324 242
121	1 46 41	1 771 561	11.	4.9460 874
122	1 48 34	1 815 848	11.0453 61	4.9596 757
123	1 51 29	1 860 867	11.0905 365	4.9731 898
124	1 53 76	1 906 624	11.1355 287	4.9866 31
125	1 56 25	1 953 125	11.1803 399	5.

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
126	1 58 76	2 000 376	11.2249 722	5.0132 979
127	1 61 29	2 048 383	11.2694 277	5.0265 257
128	1 63 84	2 097 152	11.3137 085	5.0396 842
129	1 66 41	2 146 689	11.3578 167	5.0527 743
130	1 69 00	2 197 000	11.4017 543	5.0657 97
131	1 71 61	2 248 091	11.4455 231	5.0787 531
132	1 74 24	2 299 968	11.4891 253	5.0916 434
133	1 76 89	2 352 637	11.5325 626	5.1044 687
134	1 79 56	2 406 104	11.5758 369	5.1172 299
135	1 82 25	2 460 375	11.6189 5	5.1299 278
136	1 84 96	2 515 456	11.6619 038	5.1425 632
137	1 87 69	2 571 353	11.7046 999	5.1551 367
138	1 90 44	2 628 072	11.7473 401	5.1676 493
139	1 93 21	2 685 619	11.7898 261	5.1801 015
140	1 96 00	2 744 000	11.8321 596	5.1924 941
141	1 98 81	2 803 221	11.8743 421	5.2048 279
142	2 01 64	2 863 288	11.9163 753	5.2171 034
143	2 04 49	2 924 207	11.9582 607	5.2293 215
144	2 07 36	2 985 984	12.	5.2414 828
145	2 10 25	3 048 625	12.0415 946	5.2535 879
146	2 13 16	3 112 136	12.0830 46	5.2656 374
147	2 16 09	3 176 523	12.1243 557	5.2776 321
148	2 19 04	3 241 792	12.1655 251	5.2895 725
149	2 22 01	3 307 949	12.2065 556	5.3014 592
150	2 25 00	3 375 000	12.2474 487	5.3132 928
151	2 28 01	3 442 951	12.2882 057	5.3250 74
152	2 31 04	3 511 008	12.3288 28	5.3368 033
153	2 34 09	3 581 577	12.3693 169	5.3484 812
154	2 37 16	3 652 264	12.4096 736	5.3601 084
155	2 40 25	3 723 875	12.4498 996	5.3716 854
156	2 43 36	3 796 416	12.4899 96	5.3832 126
157	2 46 49	3 869 893	12.5299 641	5.3946 907
158	2 49 64	3 944 312	12.5698 051	5.4061 202
159	2 52 81	4 019 679	12.6095 202	5.4175 015
160	2 56 00	4 096 000	12.6491 106	5.4288 352
161	2 59 21	4 173 281	12.6885 775	5.4401 218
162	2 62 44	4 251 528	12.7279 221	5.4513 618
163	2 65 69	4 330 747	12.7671 453	5.4625 556
164	2 68 96	4 410 944	12.8062 485	5.4737 037
165	2 72 25	4 492 125	12.8452 326	5.4848 066
166	2 75 56	4 574 296	12.8840 987	5.4958 647
167	2 78 89	4 657 463	12.9228 48	5.5068 784

TABLE—(Continued)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
168	2 82 24	4 741 632	12.9614 814	5.5178 484
169	2 85 61	4 826 809	13.	5.5287 748
170	2 89 00	4 913 000	13.0384 048	5.5396 583
171	2 92 41	5 000 211	13.0766 968	5.5504 991
172	2 95 84	5 088 448	13.1148 77	5.5612 978
173	2 99 29	5 177 717	13.1529 464	5.5720 546
174	3 02 76	5 268 024	13.1909 06	5.5827 702
175	3 06 25	5 359 375	13.2287 566	5.5934 447
176	3 09 76	5 451 776	13.2664 992	5.6040 787
177	3 13 29	5 545 233	13.3041 347	5.6146 724
178	3 16 84	5 639 752	13.3416 641	5.6252 263
179	3 20 41	5 735 339	13.3790 882	5.6357 408
180	3 24 00	5 832 000	13.4164 079	5.6462 162
181	3 27 61	5 929 741	13.4536 24	5.6566 528
182	3 31 24	6 028 568	13.4907 376	5.6670 511
183	3 34 89	6 128 487	13.5277 493	5.6774 114
184	3 38 56	6 229 504	13.5646 6	5.6877 34
185	3 42 25	6 331 625	13.6014 705	5.6980 192
186	3 45 96	6 434 856	13.6381 817	5.7082 675
187	3 49 69	6 539 203	13.6747 943	5.7184 791
188	3 53 44	6 644 672	13.7113 092	5.7286 543
189	3 57 21	6 751 269	13.7477 271	5.7387 936
190	3 61 00	6 859 000	13.7840 488	5.7488 971
191	3 64 81	6 967 871	13.8202 75	5.7589 652
192	3 68 64	7 077 888	13.8564 065	5.7689 982
193	3 72 49	7 189 057	13.8924 4	5.7789 966
194	3 76 36	7 301 384	13.9283 883	5.7889 604
195	3 80 25	7 414 875	13.9642 4	5.7988 9
196	3 84 16	7 529 536	14.	5.8087 857
197	3 88 09	7 645 373	14.0356 688	5.8186 479
198	3 92 04	7 762 392	14.0712 473	5.8284 867
199	3 96 01	7 880 599	14.1067 36	5.8382 725
200	4 00 00	8 000 000	14.1421 356	5.8480 355
201	4 04 01	8 120 601	14.1774 469	5.8577 66
202	4 08 04	8 242 408	14.2126 704	5.8674 673
203	4 12 09	8 365 427	14.2478 068	5.8771 307
204	4 16 16	8 489 664	14.2828 569	5.8867 653
205	4 20 25	8 615 125	14.3178 211	5.8963 685
206	4 24 36	8 741 816	14.3527 001	5.9059 406
207	4 28 49	8 869 743	14.3874 946	5.9154 817
208	4 32 64	8 998 912	14.4222 051	5.9249 921
209	4 36 81	9 129 329	14.4568 323	5.9344 721

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
210	4 41 00	9 261 000	14.4913 767	5.9439 22
211	4 45 21	9 393 931	14.5258 39	5.9533 418
212	4 49 44	9 528 128	14.5602 198	5.9627 32
213	4 53 69	9 663 597	14.5945 195	5.9720 926
214	4 57 96	9 800 344	14.6287 388	5.9814 24
215	4 62 25	9 938 375	14.6628 783	5.9907 264
216	4 66 56	10 077 696	14.6969 385	6.
217	4 70 89	10 218 313	14.7309 199	6.0092 45
218	4 75 24	10 360 232	14.7648 231	6.0184 617
219	4 79 61	10 503 459	14.7986 486	6.0276 502
220	4 84 00	10 648 000	14.8323 97	6.0368 107
221	4 88 41	10 793 861	14.8660 687	6.0459 435
222	4 92 84	10 941 048	14.8996 644	6.0550 489
223	4 97 29	11 089 567	14.9331 845	6.0641 27
224	5 01 76	11 239 424	14.9666 295	6.0731 779
225	5 06 25	11 390 625	15.	6.0822 02
226	5 10 76	11 543 176	15.0332 964	6.0911 994
227	5 15 29	11 697 083	15.0665 192	6.1001 702
228	5 19 84	11 852 352	15.0996 689	6.1091 147
229	5 24 41	12 008 989	15.1327 46	6.1180 332
230	5 29 00	12 167 000	15.1657 509	6.1269 257
231	5 33 61	12 326 391	15.1986 842	6.1357 924
232	5 38 24	12 487 168	15.2315 462	6.1446 337
233	5 42 89	12 649 337	15.2643 375	6.1534 495
234	5 47 56	12 812 904	15.2970 585	6.1622 401
235	5 52 25	12 977 875	15.3297 097	6.1710 058
236	5 56 96	13 144 256	15.3622 915	6.1797 466
237	5 61 69	13 312 053	15.3948 043	6.1884 628
238	5 66 44	13 481 272	15.4272 486	6.1971 544
239	5 71 21	13 651 919	15.4596 248	6.2058 218
240	5 76 00	13 824 000	15.4919 334	6.2144 65
241	5 80 81	13 997 521	15.5241 747	6.2230 843
242	5 85 64	14 172 488	15.5563 492	6.2316 797
243	5 90 49	14 348 907	15.5884 573	6.2402 515
244	5 95 36	14 526 784	15.6204 994	6.2487 998
245	6 00 25	14 706 125	15.6524 758	6.2573 248
246	6 05 16	14 886 936	15.6843 871	6.2658 266
247	6 10 09	15 069 223	15.7162 336	6.2743 054
248	6 15 04	15 252 992	15.7480 157	6.2827 613
249	6 20 01	15 438 249	15.7797 338	6.2911 946
250	6 25 00	15 625 000	15.8113 883	6.2996 053
251	6 30 01	15 813 251	15.8429 795	6.3079 935

TABLE—(Continued)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
252	6 35 04	16 003 008	15.8745 079	6.3163 596
253	6 40 09	16 194 277	15.9059 737	6.3247 035
254	6 45 16	16 387 064	15.9373 775	6.3330 256
255	6 50 25	16 581 375	15.9687 194	6.3413 257
256	6 55 36	16 777 216	16.	6.3496 042
257	6 60 49	16 974 593	16.0312 195	6.3578 611
258	6 65 64	17 173 512	16.0623 784	6.3660 968
259	6 70 81	17 373 979	16.0934 769	6.3743 111
260	6 76 00	17 576 000	16.1245 155	6.3825 043
261	6 81 21	17 779 581	16.1554 944	6.3906 765
262	6 86 44	17 984 728	16.1864 141	6.3988 279
263	6 91 69	18 191 447	16.2172 747	6.4069 585
264	6 96 96	18 399 744	16.2480 768	6.4150 687
265	7 02 25	18 609 625	16.2788 206	6.4231 583
266	7 07 56	18 821 096	16.3095 064	6.4312 276
267	7 12 89	19 034 163	16.3401 346	6.4392 767
268	7 18 24	19 248 832	16.3707 055	6.4473 057
269	7 23 61	19 465 109	16.4012 195	6.4553 148
270	7 29 00	19 683 000	16.4316 767	6.4633 041
271	7 34 41	19 902 511	16.4620 776	6.4712 736
272	7 39 84	20 123 648	16.4924 225	6.4792 236
273	7 45 29	20 346 417	16.5227 116	6.4871 541
274	7 50 76	20 570 824	16.5529 454	6.4950 653
275	7 56 25	20 796 875	16.5831 24	6.5029 572
276	7 61 76	21 024 576	16.6132 477	6.5108 3
277	7 67 29	21 253 933	16.6433 17	6.5186 839
278	7 72 84	21 484 952	16.6783 32	6.5265 189
279	7 78 41	21 717 639	16.7032 931	6.5343 351
280	7 84 00	21 952 000	16.7332 005	6.5421 326
281	7 89 61	22 188 041	16.7630 546	6.5499 116
282	7 95 24	22 425 768	16.7928 556	6.5576 722
283	8 00 89	22 665 187	16.8226 038	6.5654 144
284	8 06 56	22 906 304	16.8522 995	6.5731 385
285	8 12 25	23 149 125	16.8819 43	6.5808 443
286	8 17 96	23 393 656	16.9115 345	6.5885 323
287	8 23 69	23 639 903	16.9410 743	6.5962 023
288	8 29 44	23 887 872	16.9705 627	6.6038 545
289	8 35 21	24 137 569	17.	6.6114 89
290	8 41 00	24 389 000	17.0293 864	6.6191 06
291	8 46 81	24 642 171	17.0587 221	6.6267 054
292	8 52 64	24 897 088	17.0880 075	6.6342 874
293	8 58 49	25 153 757	17.1172 428	6.6418 522

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
294	8 64 36	25 412 184	17.1464 282	6.6493 998
295	8 70 25	25 672 375	17.1755 64	6.6569 302
296	8 76 16	25 934 336	17.2046 505	6.6644 437
297	8 82 09	26 198 073	17.2336 879	6.6719 403
298	8 88 04	26 463 592	17.2626 765	6.6794 2
299	8 94 01	26 730 899	17.2916 165	6.6868 831
300	9 00 00	27 000 000	17.3205 081	6.6943 295
301	9 06 01	27 270 901	17.3493 516	6.7017 593
302	9 12 04	27 543 608	17.3781 472	6.7091 729
303	9 18 09	27 818 127	17.4068 952	6.7165 7
304	9 24 16	28 094 464	17.4355 958	6.7239 508
305	9 30 25	28 372 625	17.4642 492	6.7313 155
306	9 36 36	28 652 616	17.4928 557	6.7386 641
307	9 42 49	28 934 443	17.5214 155	6.7459 967
308	9 48 64	29 218 112	17.5499 288	6.7533 134
309	9 54 81	29 503 609	17.5783 958	6.7606 143
310	9 61 00	29 791 000	17.6068 169	6.7678 995
311	9 67 21	30 080 231	17.6151 921	6.7751 69
312	9 73 44	30 371 328	17.6635 217	6.7824 229
313	9 79 69	30 664 297	17.6918 06	6.7896 613
314	9 85 96	30 959 144	17.7200 451	6.7968 844
315	9 92 25	31 255 875	17.7482 393	6.8040 921
316	9 98 56	31 554 496	17.7763 888	6.8112 847
317	10 04 89	31 855 013	17.8044 938	6.8184 62
318	10 11 24	32 157 432	17.8325 545	6.8256 242
319	10 17 61	32 461 759	17.8605 711	6.8327 714
320	10 24 00	32 768 000	17.8885 438	6.8399 037
321	10 30 41	33 076 161	17.9164 729	6.8470 213
322	10 36 84	33 386 248	17.9443 584	6.8541 24
323	10 43 29	33 698 267	17.9722 008	6.8612 12
324	10 49 76	34 012 224	18.	6.8682 855
325	10 56 25	34 328 125	18.0277 564	6.8753 433
326	10 62 76	34 645 976	18.0554 701	6.8823 888
327	10 69 29	34 965 783	18.0831 413	6.8894 188
328	10 75 84	35 287 552	18.1107 703	6.8964 345
329	10 82 41	35 611 289	18.1383 571	6.9034 359
330	10 89 00	35 937 000	18.1659 021	6.9104 232
331	10 95 61	36 264 691	18.1934 054	6.9173 964
332	11 02 24	36 594 368	18.2208 672	6.9243 556
333	11 08 89	36 926 037	18.2482 876	6.9313 088
334	11 15 56	37 259 704	18.2756 669	6.9382 321
335	11 22 25	37 595 375	18.3030 052	6.9451 496

TABLE—(Continued)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
336	11 28 96	37 933 056	18.3303 028	6.9520 533
337	11 35 69	38 272 753	18.3575 598	6.9589 434
338	11 42 44	38 614 472	18.3847 763	6.9658 198
339	11 49 21	38 958 219	18.4119 526	6.9726 826
340	11 56 00	39 304 000	18.4390 889	6.9795 321
341	11 62 81	39 651 821	18.4661 853	6.9863 681
342	11 69 64	40 001 688	18.4932 42	6.9931 906
343	11 76 49	40 353 607	18.5202 592	7.
344	11 83 36	40 707 584	18.5472 37	7.0067 962
345	11 90 25	41 063 625	18.5741 756	7.0135 791
346	11 97 16	41 421 736	18.6010 752	7.0203 49
347	12 04 09	41 781 923	18.6279 36	7.0271 058
348	12 11 04	42 144 192	18.6547 581	7.0338 497
349	12 18 01	42 508 549	18.6815 417	7.0405 806
350	12 25 00	42 875 000	18.7082 869	7.0472 987
351	12 32 01	43 243 551	18.7349 94	7.0540 041
352	12 39 04	43 614 208	18.7616 63	7.0606 967
353	12 46 09	43 986 977	18.7882 942	7.0673 767
354	12 53 16	44 361 864	18.8148 877	7.0740 44
355	12 60 25	44 738 875	18.8414 437	7.0806 988
356	12 67 36	45 118 016	18.8679 623	7.0873 411
357	12 74 49	45 499 293	18.8944 436	7.0939 709
358	12 81 64	45 882 712	18.9208 879	7.1005 885
359	12 88 81	46 268 279	18.9472 953	7.1071 937
360	12 96 00	46 656 000	18.9736 66	7.1137 866
361	13 03 21	47 045 831	19.	7.1203 674
362	13 10 44	47 437 928	19.0262 976	7.1269 36
363	13 17 69	47 832 147	19.0525 589	7.1334 925
364	13 24 96	48 228 544	19.0787 84	7.1400 37
365	13 32 25	48 627 125	19.1049 732	7.1465 695
366	13 39 56	49 027 896	19.1311 265	7.1530 901
367	13 46 89	49 430 863	19.1572 441	7.1595 988
368	13 54 24	49 836 032	19.1833 261	7.1660 957
369	13 61 61	50 243 409	19.2093 727	7.1725 809
370	13 69 00	50 653 000	19.2353 841	7.1790 544
371	13 76 41	51 064 811	19.2613 603	7.1855 162
372	13 83 84	51 478 848	19.2873 015	7.1919 663
373	13 91 29	51 895 117	19.3132 079	7.1984 05
374	13 98 76	52 313 624	19.3390 796	7.2048 322
375	14 06 25	52 734 375	19.3649 167	7.2112 479
376	14 13 76	53 157 376	19.3907 194	7.2176 522
377	14 21 29	53 582 633	19.4164 878	7.2240 45

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
378	14 28 84	54 010 152	19.4422 221	7.2304 268
379	14 36 41	54 439 939	19.4679 223	7.2367 972
380	14 44 00	54 872 000	19.4935 887	7.2431 565
381	14 51 61	55 306 341	19.5192 213	7.2495 045
382	14 59 24	55 742 968	19.5448 203	7.2558 415
383	14 66 89	56 181 887	19.5703 858	7.2621 675
384	14 74 56	56 623 104	19.5959 179	7.2684 824
385	14 82 25	57 066 625	19.6214 169	7.2747 864
386	14 89 96	57 512 456	19.6468 827	7.2810 794
387	14 97 69	57 960 603	19.6723 156	7.2873 617
388	15 05 44	58 411 072	19.6977 156	7.2936 33
389	15 13 21	58 863 869	19.7230 829	7.2998 936
390	15 21 00	59 319 000	19.7484 177	7.3061 436
391	15 28 81	59 776 471	19.7737 199	7.3123 828
392	15 36 64	60 236 288	19.7989 899	7.3186 114
393	15 44 49	60 698 457	19.8242 276	7.3248 295
394	15 52 36	61 162 984	19.8494 332	7.3310 369
395	15 60 25	61 629 875	19.8746 069	7.3372 339
396	15 68 16	62 099 136	19.8997 487	7.3434 205
397	15 76 09	62 570 773	19.9248 588	7.3495 966
398	15 84 04	63 044 792	19.9499 373	7.3557 624
399	15 92 01	63 521 199	19.9749 844	7.3619 178
400	16 00 00	64 000 000	20.	7.3680 63
401	16 08 01	64 481 201	20.0249 844	7.3741 979
402	16 16 04	64 964 808	20.0499 377	7.3803 227
403	16 24 09	65 450 827	20.0748 599	7.3864 373
404	16 32 16	65 939 264	20.0997 512	7.3925 418
405	16 40 25	66 430 125	20.1246 118	7.3986 363
406	16 48 36	66 923 416	20.1494 417	7.4047 206
407	16 56 49	67 419 143	20.1742 41	7.4107 95
408	16 64 64	67 917 312	20.1990 099	7.4168 595
409	16 72 81	68 417 929	20.2237 484	7.4229 142
410	16 81 00	68 921 000	20.2484 567	7.4289 589
411	16 89 21	69 426 531	20.2731 349	7.4349 938
412	16 97 44	69 934 528	20.2977 831	7.4410 189
413	17 05 69	70 444 997	20.3224 014	7.4470 342
414	17 13 96	70 957 944	20.3469 899	7.4530 399
415	17 22 25	71 473 375	20.3715 488	7.4590 359
416	17 30 56	71 991 296	20.3960 781	7.4650 223
417	17 38 89	72 511 713	20.4205 779	7.4709 991
418	17 47 24	73 034 632	20.4450 483	7.4769 664
419	17 55 61	73 560 059	20.4694 895	7.4829 242

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
420	17 64 00	74 088 000	20.4939 015	7.4888 724
421	17 72 41	74 618 461	20.5182 845	7.4948 113
422	17 80 84	75 151 448	20.5426 386	7.5007 406
423	17 89 29	75 686 967	20.5669 638	7.5066 607
424	17 97 76	76 225 024	20.5912 603	7.5125 715
425	18 06 25	76 765 625	20.6155 281	7.5184 73
426	18 14 76	77 308 776	20.6397 674	7.5243 652
427	18 23 29	77 854 483	20.6639 783	7.5302 482
428	18 31 84	78 402 752	20.6881 609	7.5361 221
429	18 40 41	78 953 589	20.7123 152	7.5419 867
430	18 49 00	79 507 000	20.7364 414	7.5478 423
431	18 57 61	80 062 991	20.7605 395	7.5536 888
432	18 66 24	80 621 568	20.7846 097	7.5595 263
433	18 74 89	81 182 737	20.8086 52	7.5653 548
434	18 83 56	81 746 504	20.8326 667	7.5711 743
435	18 92 25	82 312 875	20.8566 536	7.5769 849
436	19 00 96	82 881 856	20.8806 13	7.5827 865
437	19 09 69	83 453 453	20.9045 45	7.5885 793
438	19 18 44	84 027 672	20.9284 495	7.5943 633
439	19 27 21	84 604 519	20.9523 268	7.6001 385
440	19 36 00	85 184 000	20.9761 77	7.6059 049
441	19 44 81	85 766 121	21.	7.6116 626
442	19 53 64	86 350 888	21.0237 96	7.6174 116
443	19 62 49	86 938 307	21.0475 652	7.6231 519
444	19 71 36	87 528 384	21.0713 075	7.6288 837
445	19 80 25	88 121 125	21.0950 231	7.6346 067
446	19 89 16	88 716 536	21.1187 121	7.6403 213
447	19 98 09	89 314 623	21.1423 745	7.6460 272
448	20 07 04	89 915 392	21.1660 105	7.6517 247
449	20 16 01	90 518 849	21.1896 201	7.6574 138
450	20 25 00	91 125 000	21.2132 034	7.6630 943
451	20 34 01	91 733 851	21.2367 606	7.6687 665
452	20 43 04	92 345 408	21.2602 916	7.6744 303
453	20 52 09	92 959 677	21.2837 967	7.6800 857
454	20 61 16	93 576 664	21.3072 758	7.6857 328
455	20 70 25	94 196 375	21.3307 29	7.6913 717
456	20 79 36	94 818 816	21.3541 565	7.6970 023
457	20 88 49	95 443 993	21.3775 583	7.7026 246
458	20 97 64	96 071 912	21.4009 346	7.7082 388
459	21 06 81	96 702 579	21.4242 853	7.7138 448
460	21 16 00	97 336 000	21.4476 106	7.7194 426
461	21 25 21	97 972 181	21.4709 106	7.7250 325

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
462	21 34 44	98 611 128	21.4941 853	7.7306 141
463	21 43 69	99 252 847	21.5174 348	7.7361 877
464	21 52 96	99 897 344	21.5406 592	7.7417 532
465	21 62 25	100 544 625	21.5638 587	7.7473 109
466	21 71 56	101 194 696	21.5870 331	7.7528 606
467	21 80 89	101 847 563	21.6101 828	7.7584 023
468	21 90 24	102 503 232	21.6333 077	7.7639 361
469	21 99 61	103 161 709	21.6564 078	7.7694 62
470	22 09 00	103 823 000	21.6794 834	7.7749 801
471	22 18 41	104 487 111	21.7025 344	7.7804 904
472	22 27 84	105 154 048	21.7255 31	7.7859 928
473	22 37 29	105 823 817	21.7485 632	7.7914 875
474	22 46 76	106 496 424	21.7715 411	7.7969 745
475	22 56 25	107 171 875	21.7944 947	7.8024 538
476	22 65 76	107 850 176	21.8174 242	7.8079 254
477	22 75 29	108 531 333	21.8403 297	7.8133 892
478	22 84 84	109 215 352	21.8632 111	7.8188 456
479	22 94 41	109 902 239	21.8860 686	7.8242 942
480	23 04 00	110 592 000	21.9089 023	7.8297 353
481	23 13 61	111 284 641	21.9317 122	7.8351 688
482	23 23 24	111 980 168	21.9544 984	7.8405 949
483	23 32 89	112 678 587	21.9772 61	7.8460 134
484	23 42 56	113 379 904	22.	7.8514 244
485	23 52 25	114 084 125	22.0227 155	7.8568 281
486	23 61 96	114 791 256	22.0454 077	7.8622 242
487	23 71 69	115 501 303	22.0680 765	7.8676 13
488	23 81 44	116 214 272	22.0907 22	7.8729 944
489	23 91 21	116 930 169	22.1133 444	7.8783 684
490	24 01 00	117 649 000	22.1359 436	7.8837 352
491	24 10 81	118 370 771	22.1585 198	7.8890 946
492	24 20 64	119 095 488	22.1810 73	7·8944 468
493	24 30 49	119 823 157	22.2036 033	7.8997 917
494	24 40 36	120 553 784	22.2261 108	7.9051 294
495	24 50 25	121 287 375	22.2485 955	7.9104 599
496	24 60 16	122 023 936	22.2710 575	7.9157 832
497	24 70 09	122 763 473	22.2934 968	7.9210 994
498	24 80 04	123 505 992	22.3159 136	7.9264 085
499	24 90 01	124 251 499	22.3383 079	7.9317 104
500	25 00 00	125 000 000	22.3606 798	7.9370 053
501	25 10 01	125 751 501	22.3830 293	7.9422 931
502	25 20 04	126 506 008	22.4053 565	7.9475 739
503	25 30 09	127 263 527	22.4276 615	7.9528 477

TABLE—*(Continued)*

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
504	25 40 16	128 024 064	22.4499 443	7.9581 144
505	25 50 25	128 787 625	22.4722 051	7.9633 743
506	25 60 36	129 554 246	22.4944 438	7.9686 271
507	25 70 49	130 323 843	22.5166 605	7.9738 731
508	25 80 64	131 096 512	22.5388 553	7.9791 122
509	25 90 81	131 872 229	22.5610 283	7.9843 444
510	26 01 00	132 651 000	22.5831 796	7.9895 697
511	26 11 21	133 432 [illegible]	22.6053 091	7.9947 883
512	26 21 44	134 217 [illegible]	22.6274 17	8.
513	26 31 69	135 005 [illegible]	22.6495 033	8.0052 049
514	26 41 96	135 796 744	22.6715 681	8.0104 032
515	26 52 25	136 590 875	22.6936 114	8.0155 946
516	26 62 56	137 388 096	22.7156 334	8.0207 794
517	26 72 89	138 188 413	22.7376 340	8.0259 574
518	26 83 24	138 991 832	22.7596 134	8.0311 287
519	26 93 61	139 798 359	22.7815 715	8.0362 935
520	27 04 00	140 608 000	22.8035 085	8.0414 515
521	27 14 41	141 420 761	22.8254 244	8.0466 03
522	27 24 84	142 236 648	22.8473 193	8.0517 479
523	27 35 29	143 055 667	22.8691 933	8.0568 862
524	27 45 76	143 877 824	22.8910 463	8.0620 18
525	27 56 25	144 703 125	22.9128 785	8.0671 432
526	27 66 76	145 531 576	22.9346 899	8.0722 62
527	27 77 29	146 363 183	22.9564 806	8.0773 743
528	27 87 84	147 197 952	22.9782 506	8.0824 8
529	27 98 41	148 035 889	23.	8.0875 794
530	28 09 00	148 877 000	23.0217 289	8.0926 723
531	28 19 61	149 721 291	23.0434 372	8.0977 589
532	28 30 24	150 568 768	23.0651 252	8.1028 39
533	28 40 89	151 419 437	23.0867 928	8.1079 128
534	28 51 56	152 273 304	23.1084 4	8.1129 803
535	28 62 25	153 130 375	23.1300 67	8.1180 414
536	28 72 96	153 990 656	23.1516 738	8.1230 962
537	28 83 69	154 854 153	23.1732 605	8.1281 447
538	28 94 44	155 720 872	23.1948 37	8.1331 87
539	29 05 21	156 590 819	23.2163 735	8.1382 23
540	29 16 00	157 464 000	23.2379 001	8.1432 529
541	29 26 81	158 340 421	23.2594 067	8.1482 765
542	29 37 64	159 220 088	23.2808 935	8.1532 939
543	29 48 49	160 103 007	23.3023 604	8.1583 051
544	29 59 36	160 989 184	23.3238 076	8.1633 102
	29 70 25	161 878 625	23.3452 351	8.1683 092

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
546	29 81 16	162 771 336	23.3666 429	8.1733 02
547	29 92 09	163 667 323	23.3880 311	8.1782 888
548	30 03 04	164 566 592	23.4093 998	8.1832 695
549	30 14 01	165 469 149	23.4307 49	8.1882 441
550	30 25 00	166 375 000	23.4520 788	8.1932 127
551	30 36 01	167 284 151	23.4733 892	8.1981 753
552	30 47 04	168 196 608	23.4946 802	8.2031 319
553	30 58 09	169 112 377	23.5159 52	8.2080 825
554	30 69 16	170 031 464	23.5372 046	8.2130 271
555	30 80 25	170 953 875	23.5584 38	8.2179 657
556	30 91 36	171 879 616	23.5796 522	8.2228 985
557	31 02 49	172 808 693	23.6008 474	8.2278 254
558	31 13 64	173 741 112	23.6220 236	8.2327 463
559	31 24 81	174 676 879	23.6431 808	8.2376 614
560	31 36 00	175 616 000	23.6643 191	8.2425 706
561	31 47 21	176 558 481	23.6854 386	8.2474 74
562	31 58 44	177 504 328	23.7065 392	8.2523 715
563	31 69 69	178 453 547	23.7276 21	8.2572 635
564	31 80 96	179 406 144	23.7486 842	8.2621 492
565	31 92 25	180 362 125	23.7697 286	8.2670 294
566	32 03 56	181 321 496	23.7907 545	8.2719 039
567	32 14 89	182 284 263	23.8117 618	8.2767 726
568	32 26 24	183 250 432	23.8327 506	8.2816 255
569	32 37 61	184 220 009	23.8537 209	8.2864 928
570	32 49 00	185 193 000	23,8746 728	8.2913 444
571	32 60 41	186 169 411	23.8956 063	8.2961 903
572	32 71 84	187 149 248	23.9165 215	8.3010 304
573	32 83 29	188 132 517	23.9374 184	8.3058 651
574	32 94 76	189 119 224	23.9582 971	8.3106 941
575	33 06 25	190 109 375	23.9791 576	8.3155 175
576	33 17 76	191 102 976	24.	8.3203 353
577	33 29 29	192 100 033	24.0208 243	8.3251 475
578	33 40 84	193 100 552	24.0416 306	8.3299 542
579	33 52 41	194 104 539	24.0624 188	8.3347 553
580	33 64 00	195 112 000	24.0831 891	8.3395 509
581	33 75 61	196 122 941	24.1039 416	8.3443 41
582	33 87 24	197 137 368	24.1246 762	8.3491 256
583	33 98 89	198 155 287	24.1453 929	8.3539 047
584	34 10 56	199 176 704	24.1660 919	8.3586 784
585	34 22 25	200 201 625	24.1867 732	8.3634 466
586	34 33 96	201 230 056	24.2074 369	8.3682 095
587	34 45 69	202 262 003	24.2280 829	8.3729 668

TABLE—(Concluded)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
588	34 57 44	203 297 472	24.2487 113	8.3777 188
589	34 69 21	204 336 469	24.2693 222	8.3824 653
590	34 81 00	205 379 000	24.2899 156	8.3872 065
591	34 92 81	206 425 071	24.3104 916	8.3919 423
592	35 04 64	207 474 688	24.3310 501	8.3966 729
593	35 16 49	208 527 857	24.3515 913	8.4013 981
594	35 28 36	209 584 584	24.3721 152	8.4061 180
595	35 40 25	210 644 875	24.3926 218	8.4108 326
596	35 52 16	211 708 736	24.4131 112	8.4155 419
597	35 64 09	212 776 173	24.4335 834	8.4202 46
598	35 76 04	213 847 192	24.4540 385	8.4249 448
599	35 88 01	214 921 799	24.4744 765	8.4296 383
600	36 00 00	216 000 000	24.4948 974	8.4343 267
601	36 12 01	217 081 801	24.5153 013	8.4390 098
602	36 24 04	218 167 208	24.5356 883	8.4436 877
603	36 36 09	219 256 227	24.5560 583	8.4483 605
604	36 48 16	220 348 864	24.5764 115	8.4530 281
605	36 60 25	221 445 125	24.5967 478	8.4576 906
606	36 72 36	222 545 016	24.6170 673	8.4623 479
607	36 84 49	223 648 543	24.6373 7	8.467
608	36 96 64	224 755 712	24.6576 56	8.4716 471
609	37 08 81	225 866 529	24.6779 254	8.4762 892
610	37 21 00	226 981 000	24.6981 781	8.4809 261
611	37 33 21	228 099 131	24.7184 142	8.4855 579
612	37 45 44	229 220 928	24.7386 338	8.4901 848
613	37 57 69	230 346 397	24.7588 368	8.4948 065
614	37 69 96	231 475 544	24.7790 234	8.4994 233
615	37 82 25	232 608 375	24.7991 935	8.5040 35
616	37 94 56	233 744 896	24.8193 473	8.5086 417
617	38 06 89	234 885 113	24.8394 847	8.5132 435
618	38 19 24	236 029 032	24.8596 058	8.5178 403
619	38 31 61	237 176 659	24.8797 106	8.5224 321
620	38 44 00	238 328 000	24.8997 992	8.5270 189

Any number multiplied into itself 3 times is cubed; as, 3×3× = 27, which is the cube of 3.

The square root of any number is that number which, multiplied into itself, will be equal to the given number; as, $\sqrt{9} = 3×3$ *hence 3 is* the square root of 9.

of Letters in Calculation.—It is extremely convenient to nt quantities by letters, as has been done in various cases arlier chapters of this book, as, for example, on pages 7, 8, l 33. On pages 7 and 8 we have the formula $h = g\frac{t^2}{2}$,

= height from which a body will fall in any number of seconds.
= number of seconds it has been falling.
= acceleration produced by gravity, which by experiment we know to be about 32.2 feet per second.

itten out in full would be $\frac{g \times t \times t}{2}$, or, in words, g multiplied ain multiplied by t, and the whole divided by 2. The ication signs are omitted in writing a formula, but are to be understood.

little index figure ² placed at the upper right hand of t same meaning as when used with a figure.

Thus 3^2 means 3 squared, or 3 × 3,
and 3^3 " 3 cubed, or 3 × 3 × 3,
so t^2 " t squared, or $t \times t$.

n a letter has a figure in front of it it means that the y represented by the letter is to be multiplied by the fig- hus 3 T means $3 \times T$, and if T had a particular value of 4 T would equal 12 feet.

her formula on page 8 is $v = \sqrt{2gh}$. This means that $v =$ are root of $2 \times g \times h$, or that two times g is multiplied by he product has its square root taken, and this square root to v.

age 10 is the formula $F = Ma$, showing the relation be- orce, *mass*, and acceleration. This means that the force is cally equal to the product of the mass by the acceleration.

Simple Equations* Used in Formulas.

An equation is an expression of equality between two quantities, thus,

$$(4 \times 6) + 38 = 193 - 131$$

is an equation. Equations, however, usually contain one or more unknown quantities, which are designated by letters. The solution of the equation means the finding of the numerical value of the unknown quantities. Thus in the above equation, if 38 were the unknown quantity the equation would be written

$$(4 \times 6) + x = 193 - 131,$$

and it would be solved by finding the true value of x. The following rules are to be used in solving equations:

Rule I.—If equal changes are made in both sides of the equation, the equality will not be disturbed. That is, we may add or subtract the same quantity to or from both sides of the equation, multiply or divide every term by the same number, raise both sides to the same power, or extract the same root of both sides, without affecting the equality. Thus in the above equation

$$(4 \times 6) + x = 193 - 131,$$

adding 100 to both sides:

$$(4 \times 6) + x + 100 = 193 - 131 + 100,$$

dividing every term by 10:

$$\frac{4 \times 6}{10} + \frac{x}{10} = 19.3 - 13.1,$$

or extracting the square root from both sides:

$$\sqrt{(4 \times 6) + x} = \sqrt{193 - 131},$$

does not in the least affect the equality.

Rule 2.—Any term, or terms, may be transposed from one side of an equation to the other, provided the sign is changed from us to minus, or *vice versa*, in transposing, without disturbing the uality, thus:

---

*Only the simplest kind of equation is considered in this book. For a more complete study of equations the reader is referred to any text book of algebra, such as Wentworth's Elementary Algebra.

$$(4 \times 6) + x = 193 - 131,$$
$$x - 193 = -(4 \times 6) - 131,$$
$$(4 \times 6) + 131 = 193 - x,$$
$$(4 \times 6) + x - 193 + 131 = 0,$$

e all equally true.

To solve a simple equation with one unknown quantity, trans-ose all of the terms containing the unknown quantity to one side f the equation, and all of the remaining terms to the other. Com-ine the terms and divide both sides by the coefficient of the nknown quantity.

Examples.—Required the value of x in

$$18x - 224 + 113 + x = (24 - x)\,2.$$

ransposing:

$$18x + x - (24 - x)\,2 = 224 - 113.$$

implifying:

$$18x + x - 48 + 2x = 224 - 113.$$

ransposing again:

$$18x + x + 2x = 224 + 48 - 113.$$

ombining terms:

$$21x = 159.$$

ividing both sides by 21, the co-efficient of x,

$x = 7\frac{4}{7}$.—*Answer.*

---

equired the value of x in

$$2x - 3(2x - 3) = 1 - 10(x - 2).$$

implifying:

$$2x - 6x + 9 = 1 - 10x + 20.$$

ransposing:

$$2x - 6x + 10x = 20 + 1 - 9.$$

ollecting terms:

$$6x = 12.$$

ividing by 6, the co-efficient of x,

$x = 2$.—*Answer.*

Example.—If a certain number is increased by 16, the sum will be seven times as great as one-third of the number. Required the number. Let $x =$ the number.

Then since $(x + 16)$ is seven times as great as one-third of the number, we have

$$(x + 16) = 7 \times \tfrac{1}{3} x,$$

or

$$x + 16 = \frac{7x}{3}.$$

First multiply every term by 3 to clear the equation of fractions:

$$3x + 48 = 7x.$$

Transposing and collecting terms:

$$48 = 4x,$$

and hence

$$x = 12.\text{—}\textit{Answer.}$$

Example.—If the circumference of the driving wheel of a locomotive is 18 feet and that of one of the car wheels 6 feet, how far will the train have moved when the car-wheel has made 500 revolutions more than the driving-wheel?

Let $x =$ the required distance.

For each revolution of the driving-wheel the train moves a distance of 18 feet, and for each revolution of the car wheel the train moves a distance of 6 feet. Hence we have for the number of revolutions made by each, while the train is moving over the distance x,

$$\frac{x}{18} \text{ and } \frac{x}{6} \text{ respectively.}$$

But the required distance x is traversed when the number of revolutions of the latter is 500 more than the former. Hence we write the equation:

$$\frac{x}{18} + 500 = \frac{x}{6}.$$

To clear of fractions, we multiply every term of the equation :

$$x + 9000 = 3x.$$

Transposing and combining:

$$2x = 9000,$$

hence $$x = 4500 \text{ feet.—} \textit{Answer.}$$

Examples of Use of Formulas.—On pages 7 and 8 we have $h = \frac{g t^2}{2}$. Suppose we wanted to know how many seconds it would take a falling body to pass over a distance of 1660 feet. t is he quantity for which we want to solve the equation, g being known, and h being given by the conditions of the problem as 1660.

Multiplying both sides of the equation by 2 we have $2h = g t^2$.

Dividing by g we have $t^2 = \frac{2h}{g}$.

Extracting the square root $t = \sqrt{\frac{2h}{g}}$. This is in the form which we want, in order to get the value of t, which is

$$t = \sqrt{\frac{2 \times 1660}{32.2}} = 10 \text{ seconds.}$$

Logarithms.

Logarithms are intended to simplify the operations of multiplication, division, involution (raising numbers to higher powers), and evolution (extracting roots), by reducing these operations respectively to addition, subtraction, multiplication, and division.

The logarithm of a number is the power to which 10 must be raised to equal that number. It consists of two separate parts, an integral portion, called the *characteristic*, and a decimal portion, called the *mantissa.* In the tables mantissas only are given.

The characteristic or index of the logarithm is always one less than the number of figures in the number which lie to the left of the decimal point; thus take the number 958. From the table the mantissa is .98136, and since the number contains three figures to the left of the decimal point, the characteristic is 2, and hence the complete logarithm is 2.98136. If the number contained only *one figure to the left of* the decimal point, the characteristic would be 0. If the number is less than 1, its characteristic would be negative, being equal to one more than the number of ciphers before the first figure.

Hence we have, for example, by looking in the table of logarithms and by the preceding rules for the characteristic,

$$
\begin{aligned}
\log.\ 365 &= 2.56229\\
\log.\ 46.7 &= 1.66931\\
\log.\ 7.59 &= 0.88024\\
\log.\ .365 &= 0.56229-1 \text{ or } 9.56229-10\\
\log.\ .0467 &= 0.66931-2 \text{ or } 8.66931-10\\
\log.\ .00759 &= 0.88024-3 \text{ or } 7.88024-10.
\end{aligned}
$$

It will be observed that the *mantissa* of the logarithm is not affected by the number of ciphers at the *end* of the number; hence this portion of the logarithm is the same for 9 as for 90, or for 900 and for .009, etc., the characteristic only being different.

Example.—What is the logarithm of 946.2?

First, the characteristic is 2, since there are three figures to the left of the decimal point.

From the tables the mantissa of 946, the nearest number is .97589. The mantissa of 947 is .97635. The difference between the two mantissas is .00046. Now since the number 946.2 lies between 946 and 947, its logarithm must also lie between the logarithm of 946 and that of 947 and nearer that of 946. An increase in the number of one (from 946 to 947) caused, as we saw above, an increase in the mantissa of .00046. Therefore, an increase in the number of .2 (two-tenths) will cause an increase in the mantissa of $.2 \times .00046$ or .000092. Adding .00009 to .97589 we have .97598 as the mantissa of 946.2. The complete logarithm will be therefore, 2.97598. In the last column of the table of logarithms headed Prop. will be found numbers which represent the differences in mantissas corresponding to a change of one in the number, so that the labor of looking up the mantissa of the larger number and subtracting the two mantissas is avoided. Thus, suppose again that we desire the logarithm of 946.2. Log. 946 = 2.97589. In the last column we find the number 46. Place three ciphers and a decimal before it and multiply by .2. The result is .000092 as before, which must be added to 2.97589, giving as before 2.97598 as the logarithm desired.

The calculation can be put in very compact form as follows:

Required log. 946.2. Proportion, .00046
.2
.000092
log. 946 = 2.97589
2.97598—*Answer.*

Required log. 13.698. Proportion, .00323
.96
1938
2897
.0030908
log. 136 = 1.13353
1.13662—*Answer.*

To find the number corresponding to a given logarithm the process must be reversed. Look in the tables till we find the mantissa next lowest to that of the given logarithm. If an exact equal cannot be found, we can arrive at the number corresponding by the application of proportional parts.

Example.—What number corresponds to the logarithm 1.83947? Looking in the table we find there a mantissa exactly .83947. The number corresponding is 691. Since the characteristic is 1, there must be *two* figures to the left of the decimal point, so we place a decimal between 9 and 1 and obtain 69.1 as the number corresponding to the logarithm 1.83987.

Example.—What is the number corresponding to the logarithm 0.79804? The next lowest mantissa is .79796, corresponding to the number 628. The proportional number in last column is 70.

Divide .00070 by the difference between .79804 and .79796.

$$\frac{.00070}{.00008} = 9 \text{ very nearly.}$$

Annex 9 to 628, making 6289. Since the characteristic is zero, there must be one figure to the left of the decimal; therefore we put the decimal between 6 and 2 and obtain for the answer 6.289 as the number corresponding to the logarithm 0.79804.

To multiply by logarithms:

Rule.—Add together the logarithms of the factors, and the sum will be the logarithm of the product.

Example.—Multiply 79600 × 0.435.

$$\begin{array}{ll} \text{log. } 79600 = & 4.90091 \\ \text{log. } \quad .435 = & \underline{.63848 - 1} \\ & 5.53939 - 1 = 4.53939 = \text{log. } 34690 \\ & \quad 34690\text{—}\textit{Answer.} \end{array}$$

To divide by logarithms:

Rule.—From the logarithm of the dividend deduct the logarithm of the divisor, and the difference will be the logarithm of the quotient.

Examples.—Divide 43800 by 368.

$$\begin{array}{rl} \text{log. } 43800 = & 4.64147 \\ \text{log. } \quad 368 = & \underline{2.56584} \\ & 2.07563 = \text{log. } 119 \\ & \quad 119\text{—}\textit{Answer.} \end{array}$$

Divide .05638 by 250.

$$\begin{array}{rll} \text{log. } .05638 = & 0.75112 - 2 = & 8.75112 - 10 \\ \text{log. } \quad 25 = & \underline{2.39794} \quad = & \underline{2.39794} \\ & & 6.35318 - 10 \end{array}$$

Or $.35318 - 4 = \text{log. } .0002255$

.0002255—*Answer.*

Raising to Powers—Involution by Logarithms.—

Rule.—Multiply the logarithm of the number by the power to *which it is to* be raised, and the product will be the logarithm of *the required* power of the number.

Example.—What is the third power of 619?

$$\begin{array}{r}
\log.\ 619 = 2.79169 \\
3 \\
\hline
8.37507 = \log.\ 23780000.^{*}
\end{array}$$

Extracting Roots—Evolution by Logarithms.—

Rule.—Divide the logarithm of the number by the index of the ot which is to be extracted and the quotient will be the logahm of the required root.

Example.—What is the seventh root of .08937?

$$\log.\ .08937 = 0.95119 - 2.$$

Since the negative index is not evenly divisible by 7, the root be extracted, it is customary to add a number until it becomes visible, which may be done without altering the logarithm, thus:

$$\log.\ .08937 = 0.95119 = 5.95119 - 7$$

Dividing by 7 we have $0.85017 - 1 = \log.\ \sqrt[7]{.08937}$
$= \log.\ .70821.$—*Answer.*

Example.—Find by logarithms the value of

$$\frac{\sqrt{2.1}\times 86\times \overline{.0034}^2}{86.8\times\sqrt[4]{150}}$$

$$\begin{array}{rl}
\tfrac{1}{2}\log.\ 2.1 = & .16111 \\
\log.\ 86 = & 1.93449 \\
2\log.\ .0034 = & 1.06296 - 6 \\
\hline
& 3.15856 - 6 \\
& 2.48254 \\
\hline
& 0.67602 - 6 = \log.\ .000004744.\text{—Answer.}
\end{array}
\qquad
\begin{array}{rl}
\log.\ 86.8 = & 1.93852 \\
\tfrac{1}{4}\log.\ 150 = & .54402 \\
\hline
& 2.48254
\end{array}$$

---

* As the table is not accurate above 5 places, we must add ciphers at the l of the results until the required number of figures, as indicated by the aracteristic, is had.

TABLE

OF LOGARITHMS OF NUMBERS FROM 0 TO 1000.*

No.	0	1	2	3	4	5	6	7	8	9
0	0	00000	30103	47712	60206	69897	77815	84510	90309	95424
10	00000	00432	00860	01283	01703	02118	02530	02938	03342	03742
11	04139	04532	04921	05307	05690	06069	06445	06818	07188	07554
12	07918	08278	08636	08990	09342	09691	10037	10380	10721	11059
13	11394	11727	12057	12385	12710	13033	13353	13672	13987	14301
14	14613	14921	15228	15533	15836	16136	16435	16731	17026	17318
15	17609	17897	18184	18469	18752	19033	19312	19590	19865	20139
16	20412	20682	20951	21218	21484	21748	22010	22271	22530	22788
17	23045	23299	23552	23804	24054	24303	24551	24797	25042	25285
18	25527	25767	26007	26245	26481	26717	26951	27184	27415	27646
19	27875	28103	28330	28555	28780	29003	29225	29446	29666	29885
20	30103	30319	30535	30749	30963	31175	31386	31597	31806	32014
21	32222	32428	32633	32838	33041	33243	33445	33646	33845	34044
22	34242	34439	34635	34830	35024	35218	35410	35602	35793	35983
23	36173	36361	36548	36735	36921	37106	37291	37474	37657	37839
24	38021	38201	38381	38560	38739	38916	39093	39269	39445	39619
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330
26	41497	41664	41830	41995	42160	42324	42488	42651	42813	42975
27	43436	43296	43456	43616	43775	43933	44090	44248	44404	44560
28	44716	44870	45024	45178	45331	45484	45636	45788	45939	46089
29	46240	46389	46538	46686	46834	46982	47129	47275	47421	47567
30	47712	47856	48000	48144	48287	48430	48572	48713	48855	48995
31	49136	49276	49415	49554	49693	49831	49968	50105	50242	50379
32	50515	50650	50785	50920	51054	51188	51321	51454	51587	51719
33	51851	51982	52113	52244	52374	52504	52633	52763	52891	53020
34	53148	53275	53102	53529	53655	53781	53907	54033	54157	54282
35	54407	54530	54654	54777	54900	55022	55145	55266	55388	55509
36	55630	55750	55870	55990	56410	56229	56348	56466	56584	56702
37	56820	56937	57054	57170	57287	57403	57518	57634	57749	57863
38	57978	58002	58206	58319	58433	58546	58658	58771	58883	58995
39	59106	59217	59328	59439	59549	59659	59769	59879	59988	60097
40	60206	60314	60422	60530	60638	60745	60852	60959	61066	61172
41	61278	61384	61489	61595	61700	61804	61909	62013	62117	62221
42	62325	62428	62531	62634	62736	62838	62941	63042	63144	63245
43	63347	63447	63548	63648	63749	63848	63948	64048	64147	64246
44	64345	64443	64542	64640	64738	64836	64933	65030	65127	65224
45	65321	65417	65513	65609	65075	65801	65896	65991	66086	66181
46	66276	66370	66464	66558	66651	66745	66838	66931	67024	67117
47	67210	67302	67394	67486	67577	67669	67760	67851	67942	68033
48	68124	68214	68304	68394	68484	68574	68663	68752	68842	68930
49	69020	69108	69196	69284	69372	69460	69548	69635	69722	69810
50	69897	69983	70070	70156	70243	70329	70415	70500	70586	70671
51	70757	70842	70927	71011	71096	71180	71265	71349	71433	71516
52	71600	71683	71767	71850	71933	72015	72098	72181	72263	72345
53	72428	72509	72591	72672	72754	72835	72916	72997	73078	73158
	73239	73319	73399	73480	73559	73639	73719	73798	73878	73957
	74036	74115	74193	74272	74351	74429	74507	74585	74863	74741

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* Each logarithm is supposed to have the decimal sign (·) before it.

TABLE — (*Continued.*)

No.	0	1	2	3	4	5	6	7	8	9	Prop.
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511	77
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267	75
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011	74
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742	73
60	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461	72
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169	71
62	79239	79309	79379	79448	79518	79588	79657	79726	79796	79865	70
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550	69
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224	68
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888	67
66	81954	82020	82805	82151	82216	82282	82347	82412	82477	82542	66
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187	65
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83281	64
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447	63
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064	62
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672	61
72	85733	85793	85853	85913	85973	86033	86093	86153	86213	86272	60
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864	59
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448	58
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024	57
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592	56
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153	56
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707	55
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254	54
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794	54
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855	53
83	91907	91960	92012	92064	92116	92168	92220	92272	92324	92376	52
84	92427	92479	92531	92582	92634	92685	92737	92788	92839	92890	51
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399	51
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902	50
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398	49
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376	48
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856	48
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331	48
92	96378	96426	96473	96520	96507	96614	96661	96708	96754	96801	47
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266	47
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726	46
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181	46
96	98227	98272	98317	98362	98407	98452	98497	98542	98587	98632	45
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078	45
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519	44
99	99563	99607	99657	99694	99738	99782	99825	99869	99913	99956	44

Mensuration of Surfaces and Volumes.

A polygon is a surface bounded by three or more lines which close on each other. These lines are called the sides of the polygon.

Their sum, or the distance around the figure, is called the *perimeter* of the polygon. If the sides and angles are equal, the polygon is said to be *regular*. The following varieties occur:

A triangle has 3 sides and 3 angles..........................

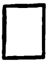
Its altitude is the perpendicular distance from the vertex of an angle to the opposite side or the opposite produced.

A quadrilateral has 4 sides and 4 angles.

A trapezoid is a quadrilateral having two of the sides parallel.

A parallelogram has the opposite sides, two and two parallel.

A rectangle is a parallelogram whose angles are all right angles.

A square is a rectangle whose sides are equal......... .... 

A pentagon has 5 sides and 5 angles..........................

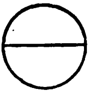
A hexagon has 6 sides and 6 angles............................

A heptagon has 7 sides and 7 angles............ ....

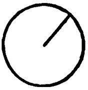
An octagon has 8 sides and 8 angles..........................

A circle is a polygon of an infinite number of sides.

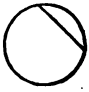
The diameter of a circle is a straight line drawn rough its centre, touching both sides, thus................



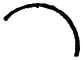
The radius of a circle is a line drawn from the centre the circumference and is half the diameter...............



A chord is a straight line joining any two points in e circumference of a circle......... ....



An arc is any part of the circumference of a circle......



A segment is the surface included between an arc and the chord ining its ends.

A sector is the surface included between an arc and the radii awn to its ends.

A prism is a solid two of whose faces are similar polygons, ing in parallel planes, and whose other sides are parallelograms. e two polygons are called the bases of the prism.

In a right prism these other sides are rectangles, the correonding sides of the polygons being vertically over each other.

A cube is a right prism whose bases are squares and whose her faces are also squares.

A pyramid is a solid whose base is a polygon and whose other ces are triangles. The vertices of these triangles meet in a mmon point. The altitude of the pyramid is the perpendicular stance from this point to the base.

A cone may be regarded as a pyramid with an infinite number triangular faces. Its base is a circle.

A right cone has its vertex perpendicularly above the centre of base. It is the solid figure which would be generated by relving a right triangle about one of the sides adjacent to the ght angle.

A cylinder may be regarded as a prism having an infinite number of faces. Its bases are circles. If the centre of the upp base is vertically over that of the lower base, it is called a righ cone.

A right cylinder is the solid which would be generated by th revolution of a rectangle about one of its sides.

A sphere is the solid generated by revolving a circle around i diameter.

A spheroid is a solid generated by the revolution of an ellip around one of its axes. It is *prolate* if the revolution is mad around the shorter axis of the ellipse, and *oblate* if around th other axis.

Rules.

To find the area of a triangle, multiply the base by the altitude and take half the product.

To find the area of any quadrilateral figure, divide the quadrilateral into two triangles; the sum of the areas of the triangles i the area.

To find the area of any polygon, divide the polygon into tria gles and trapezoids by drawing diagonals; find the areas of thes as above shown, for the area.

To find the area of a regular polygon, multiply half th perimeter of the polygon by the perpendicular drawn from th centre to the centre of one of the sides.

To find the area of a trapezoid, multiply half the sum of th parallel sides by the perpendicular distance between them; th product will be the area.

To find the area of a parallelogram, multiply the length by th height or perpendicular breadth.

To find the circumference of a circle, multiply the diameter 3 1416; the product is the circumference.

To find the diameter of a circle, divide the circumference 3·1416, the quotient is the diameter; or multiply the square ro of the area by 1·12837, the product is the diameter.

To find the area of a circle, multiply the square of the dia *by* ·7854, the product is the area; or multiply half the mference by half the diameter, the product is the area; or multiply the diameter by the circumference, and divide by 4; the otient is the area.

To find the area of a sector of a circle, multiply half the length the arc of the sector by the radius. Or, multiply the number degrees in the arc by the square of the radius, and by ·008727.

To find the area of a segment of a circle, find the area of the ctor which has the same arc as the segment; also the area of the iangle formed by the radial sides of the sector and the chord the arc; the difference or the sum of these areas will be the ea of the segment, according as it is less or greater than a semircle.

To find the area of an ellipse or oval, multiply the long diamer by the short diameter; multiply this product by ·7854, and e product will be the superficial area of the ellipse.

To find the circumference of an ellipse or oval, add the squares the long and short diameters, divide the sum by 2, extract the uare root, and multiply by 3·1416.

To find the area of any irregular figure divide it by parallel nes at equal distances from each other. The small sections thus rmed may be considered to be trapezoids and their areas sepately calculated by the rule for trapezoids. The sum of the areas the assumed trapezoids will be quite accurately the area of the gure. If a planimeter is available, this will measure the area. nother method is to draw or copy the figure on cross-section aper and count the number of small squares enclosed by it, computing the total area from their number.

To find the surface of a prism or a cylinder, the perimeter of e end multiplied by the height gives the upright surface; add vice the area of an end.

To find the surface of a pyramid or a cone, multiply the perneter of the base by half the slant height, and add the area of e base.

To find *the cubic contents* of a prism or a cylinder, multiply *e area of the base by* the height.

To find the cubic contents of a pyramid or a cone, multiply th area of the base by one-third of the perpendicular height.

To find the surface of a frustum of a pyramid or a cone, multiply the sum of the perimeters of the ends by half the sl height, and add the areas of the ends.

To find the cubic contents of a frustum of a pyramid or cone, add together the areas of the two ends, and the mean pr portional between them (that is, the square root of their p duct), and multiply the sum by one-third of the perpendic height.

To find the cubic contents of a segment of a sphere, from thr times the diameter of the sphere subtract twice the height of th segment; multiply the difference by the square of the heigh and by ·5236.

To find the cubic contents of a frustum or zone of a sphere.— To the sum of the squares of the radii of the ends add one-third of the square of the height; multiply the sum by the height and by 1·5708.

To find the surface of a sphere, multiply the square of the diameter by 3·1416.

To find the curve surface of any segment or zone of a sphere, multiply the diameter of the sphere by the height of the zone or segment and by 3·1416.

To find the cubic contents of a sphere, multiply the cube of the diameter by ·5236.

To find the volume of a spheroid, multiply the square of the revolving axis by the fixed axis and the product by ·5236.

To find the cubic contents of any irregular solid, fill a vessel to the brim with water; sink the body in the water, catching the water which is displaced and measuring it.

To find the cubic contents of a cask, multiply the square of the mean diameter by the length in inches and by ·0034. The *product* will be the approximate number of U. S. gallons which *will hold.*

TABLE

OF DIAMETERS AND AREAS OF SMALL CIRCLES.

M.	AREA.	DIAM.	AREA.	DIAM.	AREA.
	·0000008	·027	·0005726	·0625	·0030680
	·0000031	·028	·0006158	·065	·0033183
	·0000071	·029	·0006605	·070	·0038485
	·0000126	·030	·0007069	·075	·0044179
	·0000196	·031	·0007548	·080	·0050266
	·0000283	·03125	·0007670	·085	·0056745
	·0000385	·032	·0008043	·090	·0063617
	·0000503	·033	·0008553	·095	·0070882
	·0000639	·034	·0009079	·100	·0078540
	·0000785	·035	·0009621	·125	·0122719
	·0000950	·036	·0010179	·150	·0176715
	·0001131	·037	·0010752	·200	·0314159
	·0001327	·038	·0011341	·250	·0490875
	·0001539	·039	·0011946	·300	·0706858
	·0001767	·040	·0012566	·350	·0962115
325	·0001917	·041	·0013203	·400	·1256637
	·0002016	·042	·0013855	·450	·1590435
	·0002270	·043	·0014522	·500	·1963495
	·0002545	·044	·0015205	·550	·2375835
	·0002835	·045	·0015904	·600	·2827440
	·0003142	·046	·0016619	·650	·3318315
	·0003464	·047	·0017349	·700	·3848441
	·0003801	·048	·0018096	·750	·4417875
	·0004155	·049	·0018857	·800	·5026548
	·0004524	·050	·0019635	·850	·5674515
	·0004909	·055	·0023758	·900	·6361725
	·0005309	·060	·0028274	·950	·7088235

TABLE

CONTAINING THE DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES FROM 1/16 OF AN INCH TO 100 INCHES, ADVANCING BY 1/16 OF AN INCH UP TO 10 INCHES, AND BY 1/4 OF AN INCH FROM 10 TO 100 INCHES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
1/16	.1963	.0030	7/16	7.6576	4.6664
1/8	.3927	.0122	1/2	7.8540	4.9087
3/16	.5890	.0276	9/16	8.0503	5.1573
1/4	.7854	.0490	5/8	8.2467	5.4119
5/16	.9817	.0767	11/16	8.4430	5.6727
3/8	1.1781	.1104	3/4	8.6394	5.9395
7/16	1.3744	.1503	13/16	8.8357	6.2126
1/2	1.5708	.1963	7/8	9.0321	6.4918
9/16	1.7671	.2485	15/16	9.2284	6.7772
5/8	1.9635	.3068	3	9.4248	7.0686
11/16	2.1598	.3712	1/16	9.6211	7.3662
3/4	2.3562	.4417	1/8	9.8175	7.6699
13/16	2.5525	.5185	3/16	10.0138	7.9798
7/8	2.7489	.6013	1/4	10.2120	8.2957
15/16	2.9452	.6903	5/16	10.4065	8.6179
1	3.1416	.7854	3/8	10.6029	8.9462
1/16	3.3379	.8861	7/16	10.7992	9.2806
1/8	3.5343	.9940	1/2	10.9956	9.6211
3/16	3.7306	1.1075	9/16	11.1919	9.9678
1/4	3.9270	1.2271	5/8	11.3883	10.3206
5/16	4.1233	1.3529	11/16	11.5846	10.6796
3/8	4.3197	1.4848	3/4	11.7810	11.0446
7/16	4.5160	1.6229	13/16	11.9773	11.4159
1/2	4.7124	1.7671	7/8	12.1737	11.7932
9/16	4.9087	1.9175	15/16	12.3700	12.1768
5/8	5.1051	2.0739	4	12.5664	12.5664
11/16	5.3014	2.2365	1/16	12.7627	12.9622
3/4	5.4978	2.4052	1/8	12.9591	13.3640
13/16	5.6941	2.5801	3/16	13.1554	13.7721
7/8	5.8905	2.7611	1/4	13.3518	14.1862
15/16	6.0868	2.9483	5/16	13.5481	14.6066
2	6.2832	3.1416	3/8	13.7445	15.0331
1/16	6.4795	3.3411	7/16	13.9408	15.4657
1/8	6.6759	3.5465	1/2	14.1372	15.9043
3/16	6.8722	3.7582	9/16	14.3335	16.3492
1/4	7.0686	3.9760	5/8	14.5299	16.8001
5/16	7.2640	4.2001	11/16	14.7262	17.2573
3/8	7.4613	4.4302	3/4	14.9226	17.7205

TABLE—(*Continued*)

ONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.
Inch.			Inch.		
13/16	15.1189	18.1900	7/16	23.3656	43.4455
7/8	15.3153	18.6655	1/2	23.5620	44.1787
15/16	15.5716	19.1472	9/16	23.7583	44.9181
5	15.7080	19.6350	5/8	23.9547	45.6636
1/16	15.9043	20.1290	11/16	24.1510	46.4153
1/8	16.1007	20.6290	3/4	24.3474	47.1730
3/16	16.2970	21.1252	13/16	24.5437	47.9370
1/4	16.4934	21.6475	7/8	24.7401	48.7070
5/16	16.6897	22.1661	15/16	24.9364	49.4833
3/8	16.8861	22.6907	8	25.1328	50.2656
7/16	17.0824	23.2215	1/16	25.3291	51.0541
1/2	17.2788	23.7583	1/8	25.5255	51.8486
9/16	17.4751	24.3014	3/16	25.7218	52.8994
5/8	17.6715	24.8505	1/4	25.9182	53.4562
11/16	17.8678	25.4058	5/16	26.1145	54.2748
3/4	18.0642	25.9672	3/8	26.3109	55.0885
13/16	18.2605	26.5348	7/16	26.5072	55.9138
7/8	18.4569	27.1085	1/2	26.7036	56.7451
15/16	18.6532	27.6884	9/16	26.8999	57.5887
6	18.8496	28.2744	5/8	27.0963	58.4264
1/16	19.0459	28.8665	11/16	27.2926	59.7762
1/8	19.2423	29.4647	3/4	27.4890	60.1321
3/16	19.4386	30.0798	13/16	27.6853	60.9943
1/4	19.6350	30.6796	7/8	27.8817	61.8625
5/16	19.8313	31.2964	15/16	28.0780	62.7369
3/8	20.0277	31.9192	9	28.2744	63.6174
7/16	20.2240	32.5481	1/16	28.4707	64.5041
1/2	20.4204	33.1831	1/8	28.6671	65.3968
9/16	20.6167	33.8244	3/16	28.8634	66.2957
5/8	20.8131	34.4717	1/4	29.0598	67.2007
11/16	21.0094	35.1252	5/16	29.2561	68.1120
3/4	21.2058	35.7847	3/8	29.4525	69.0293
13/16	21.4021	36.4505	7/16	29.6488	69.9528
7/8	21.5985	37.1224	1/2	29.8452	70.8823
15/16	21.7948	37.8005	9/16	30.0415	71.8181
7	21.9912	38.4846	5/8	30.2379	72.7599
1/16	22.1875	39.1749	11/16	30.4342	73.7079
1/8	22.3839	39.8713	3/4	30.6306	74.6620
3/16	22.5802	40.5469	13/16	30.8269	75.6223
1/4	22.7766	41.2825	7/8	31.0233	76.5887
5/16	22.9729	41.9974	15/16	31.2196	77.5613
3/8	23.1693	42.7184	10	31.4160	78.5400

TABLE—(Continued)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
1/8	31.8087	80.5157	3/8	48.3021	185.6612
1/4	32.2014	82.5160	1/2	48.6948	188.6923
3/8	32.5941	84.5409	5/8	49.0875	191.7480
1/2	32.9868	86.5903	3/4	49.4802	194.8282
5/8	33.3795	88.6643	7/8	49.8729	197.9330
3/4	33.7722	90.7627	16	50.2656	201.0624
7/8	34.1649	92.8858	1/8	50.6583	204.2162
11	34.5576	95.0334	1/4	51.0510	207.3946
1/8	34.9503	97.2053	3/8	51.4437	210.5976
1/4	35.3430	99.4021	1/2	51.8364	213.8251
3/8	35.7357	101.6234	5/8	52.2291	217.0772
1/2	36.1284	103.8691	3/4	52.6218	220.3537
5/8	36.5211	106.1394	7/8	53.0145	223.6549
3/4	36.9138	108.4342	17	53.4072	226.9806
7/8	37.3065	110.7536	1/8	53.7999	230.3308
12	37.6992	113.0976	1/4	54.1926	233.7055
1/8	38.0919	115.4660	3/8	54.5853	237.1049
1/4	38.4846	117.8590	1/2	54.9780	240.5287
3/8	38.8773	120.2766	5/8	55.3707	243.9771
1/2	39.2700	122.7187	3/4	55.7634	247.4500
5/8	39.6627	125.1854	7/8	56.1561	250.9475
3/4	40.0554	127.6765	18	56.5488	254.4696
7/8	40.4481	130.1923	1/8	56.9415	258.0161
13	40.8408	132.7326	1/4	57.3342	261.5872
1/8	41.2338	135.2974	3/8	57.7269	265.1829
1/4	41.6262	137.8867	1/2	58.1196	268.8031
3/8	42.0189	140.5007	5/8	58.5123	272.4479
1/2	42.4116	143.1391	3/4	58.9056	276.1171
5/8	42.8043	145.8021	7/8	59.2977	279.8110
3/4	43.1970	148.4896	19	59.6904	283.5294
7/8	43.5897	151.2017	1/8	60.0831	287.2723
14	43.9824	153.9384	1/4	60.4758	291.0397
1/8	44.3751	156.6995	3/8	60.8685	294.8312
1/4	44.7676	159.4852	1/2	61.2612	298.6483
3/8	45.1605	162.2956	5/8	61.6539	302.4894
1/2	45.5532	165.1303	3/4	62.0466	306.3550
5/8	45.9459	167.9896	7/8	62.4393	310.2452
3/4	46.3386	170.8735	20	62.8320	314.1600
7/8	46.7313	173.7820	1/8	63.2247	318.0992
15	47.1240	176.7150	1/4	63.6174	322.0630
1/8	47.5167	179.6725	3/8	64.0101	326.0514
1/4	47.9094	182.6545	1/2	64.4028	330.0643

TABLE—(Continued)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
5/8	64.7955	334.1018	7/8	81.2889	525.8375
3/4	65.1882	338.1637	26	81.6816	530.9304
7/8	65.5809	342.2503	1/8	82.0743	536.0477
21	65.7936	346.3614	1/4	82.4670	541.1896
1/8	66.3663	350.4970	3/8	82.8597	546.3561
1/4	66.7590	354.6571	1/2	83.2524	551.5471
3/8	67.1517	358.8419	5/8	83.6451	556.7627
1/2	67.5444	363.0511	3/4	84.0378	562.0027
5/8	67.9371	367.2849	7/8	84.4305	567.2674
3/4	68.3298	371.5432	27	84.8232	572.5566
7/8	68.7225	375.8261	1/8	85.2159	577.8703
22	69.1152	380.1336	1/4	85.6086	583.2085
1/8	69.5079	384.4655	3/8	86.0013	588.5714
1/4	69.9006	388.8220	1/2	86.3940	593.9587
3/8	70.2933	393.2031	5/8	86.7867	599.3706
1/2	70.6860	397.6087	3/4	87.1794	604.8070
5/8	71.0787	402.0388	7/8	87.5721	610.2680
3/4	71.4714	406.4935	28	87.9648	615.7536
7/8	71.8641	410.9728	1/8	88.3575	621.2636
23	72.2568	415.4766	1/4	88.7502	626.7982
1/8	72.6495	420.0049	3/8	89.1429	632.3574
1/4	73.0422	424.5577	1/2	89.5356	637.9411
3/8	73.4349	429.1352	5/8	89.9283	643.5494
1/2	73.8276	433.7371	3/4	90.3210	649.1821
5/8	74.2203	438.3636	7/8	90.7137	654.8395
3/4	74.6130	443.0146	29	91.1064	660.5214
7/8	75.0057	447.6992	1/8	91.4991	666.2278
24	75.3984	452.3904	1/4	91.8918	671.9587
1/8	75.7911	457.1150	3/8	92.2845	677.7143
1/4	76.1838	461.8642	1/2	92.6772	683.4943
3/8	76.5765	466.6380	5/8	93.0699	689.2989
1/2	76.9692	471.4363	3/4	93.4626	695.1280
5/8	77.3619	476.2592	7/8	93.8553	700.9817
3/4	77.7546	481.1065	30	94.2480	706.8600
7/8	78.1473	485.9785	1/8	94.6407	712.7627
25	78.5400	490.8750	1/4	95.0334	718.6900
1/8	78.9327	495.7960	3/8	95.4261	724.6419
1/4	79.3254	500.7415	1/2	95.8188	730.6183
3/8	79.7181	505.7117	5/8	96.2115	736.6193
1/2	80.1108	510.7063	3/4	96.6042	742.6447
5/8	80.5035	515.7255	7/8	96.9969	748.6948
3/4	80.8962	520.7692	31	97.3896	754.7694

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅛	97.7823	760.8685	⅜	114.2757	1039.1946
¼	98.1750	766.9921	½	114.6684	1046.3941
⅜	98.5677	773.1404	⅝	115.0611	1053.5281
½	98.9684	779.3131	¾	115.4538	1060.7317
⅝	99.3531	785.5104	⅞	115.8465	1067.9599
¾	99.7458	791.7322	37	116.2392	1075.2126
⅞	100.1385	797.9786	⅛	116.6319	1082.4898
32	100.5312	804.2496	¼	117.0246	1089.7915
⅛	100.9240	810.5450	⅜	117.4173	1097.1179
¼	101.3166	816.8650	½	117.8100	1104.4687
⅜	101.7093	823.2096	⅝	118.2027	1111.8441
½	102.1020	829.5787	¾	118.5954	1119.2440
⅝	102.4947	835.9724	⅞	118.9881	1126.6685
¾	102.8874	842.3905	38	119.3808	1134.1176
⅞	103.2801	848.8333	⅛	119.7735	1141.5911
33	103.6728	855.3006	¼	120.1662	1149.0892
⅛	104.0655	861.7924	⅜	120.5589	1156.6119
¼	104.4582	868.3087	½	120.9516	1164.1591
⅜	104.8509	874.8497	⅝	121.3443	1171.7309
½	105.2436	881.4151	¾	121.7370	1179.3271
⅝	105.6363	888.0051	⅞	122.1297	1186.9480
¾	106.0290	894.6196	39	122.5224	1194.5934
⅞	106.4217	901.2587	⅛	122.9151	1202.2633
34	106.8144	907.9224	¼	123.3078	1209.9577
⅛	107.2071	914.6105	⅜	123.7005	1217.6768
¼	107.5998	921.3232	½	124.0932	1225.4203
⅜	107.9925	928.0605	⅝	124.4859	1233.1884
½	108.3852	934.8223	¾	124.9787	1240.9810
⅝	108.7779	941.6086	⅞	125.2713	1248.7982
¾	109.1706	948.4195	40	125.6640	1256.6400
⅞	109.5633	955.2550	⅛	126.0567	1264.5062
35	109.9560	962.1150	¼	126.4494	1272.3970
⅛	110.3487	968.9995	⅜	126.8421	1280.3124
¼	110.7414	975.9085	½	127.2348	1288.2523
⅜	111.1341	982.8422	⅝	127.6275	1296.2168
½	111.5268	989.8003	¾	128.0202	1304.2057
⅝	111.9195	996.7830	⅞	128.4129	1312.2193
¾	112.3122	1003.7902	41	128.8056	1320.2574
⅞	112.7049	1010.8220	⅛	129.1983	1328.3200
36	113.0976	1017.8784	¼	129.5910	1336.4071
⅛	113.4903	1024.9592	⅜	129.9837	1344.5189
¼	113.8830	1032.0646	½	130.3764	1352.6551

TABLE—(*Continued*)

ONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
5/8	130.7691	1360.8159	7/8	147.2625	1725.7324
3/4	131.1618	1369.0012	47	147.6552	1734.9486
7/8	131.5545	1377.2111	1/8	148.0479	1744.1893
42	131.9472	1385.4456	1/4	148.4406	1753.4545
1/8	132.3399	1393.7045	3/8	148.8333	1762.7344
1/4	132.7326	1401.9880	1/2	149.2260	1772.0587
3/8	133.1253	1410.2961	5/8	149.6187	1781.3976
1/2	133.5180	1418.6287	3/4	150.0114	1790.7610
5/8	133.9107	1426.9859	7/8	150.4041	1800.1490
3/4	134.3034	1435.3675	48	150.7968	1809.5616
7/8	134.6961	1443.7738	1/8	151.1895	1818.9986
43	135.0888	1452.2046	1/4	151.5822	1828.4602
1/8	135.4815	1460.6599	3/8	151.9749	1837.9364
1/4	135.8742	1469.1397	1/2	152.3676	1847.4571
3/8	136.2669	1477.6342	5/8	152.7603	1856.9924
1/2	136.6596	1486.1731	3/4	153.1530	1868.5521
5/8	137.0523	1494.7266	7/8	153.5457	1876.1365
3/4	137.4450	1503.3046	49	153.9384	1885.7454
7/8	137.8377	1511.9072	1/8	154.3311	1895.3788
44	138.2304	1520.5344	1/4	154.7238	1905.0367
1/8	138.6231	1529.1860	3/8	155.1165	1914.7093
1/4	139.0158	1537.8622	1/2	155.5092	1924.4263
3/8	139.4085	1546.5530	5/8	155.9019	1934.1579
1/2	139.8012	1555.2883	3/4	156.2946	1943.9140
5/8	140.1939	1564.0382	7/8	156.6873	1953.6947
3/4	140.5866	1572.8125	50	157.0800	1963.5000
7/8	140.9793	1581.6115	1/8	157.4727	1973.3297
45	141.3720	1590.4350	1/4	157.8654	1983.1840
1/8	141.7647	1599.2830	3/8	158.2581	1993.0529
1/4	142.1574	1608.1555	1/2	158.6508	2002.9663
3/8	142.5501	1617.0427	5/8	159.0435	2012.8943
1/2	142.9428	1625.9743	3/4	159.4362	2022.8467
5/8	143.3355	1634.9205	7/8	159.8289	2032.8238
3/4	143.7382	1643.8912	51	160.2216	2042.8254
7/8	144.1209	1652.8865	1/8	160.6143	2052.8515
46	144.5136	1661.9064	1/4	161.0070	2062.9021
1/8	144.9063	1670.9507	3/8	161.3997	2072.9764
1/4	145.2990	1680.0196	1/2	161.7924	2083.0771
3/8	145.6917	1689.1031	5/8	162.1851	2093.2014
1/2	146.0844	1698.2311	3/4	162.5778	2103.3502
5/8	146.4771	1707.3737	7/8	162.9705	2113.5236
3/4	*146.8698*	*1716.5407*	52	163.3632	2123.7216

TABLE—(Continued)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅛	163.7559	2133.9440	⅜	180.2493	2585.4509
¼	164.1486	2144.1910	½	180.6423	2596.7287
⅜	164.5413	2154.4626	⅝	181.0347	2608.0311
½	164.9340	2164.7587	¾	181.4274	2619.3580
⅝	165.3267	2175.0794	⅞	181.8201	2630.7095
¾	165.7194	2185.4245	58	182.2128	2642.0856
⅞	166.1121	2195.7943	⅛	182.6055	2653.4861
53	166.5048	2206.1886	¼	182.9982	2664.9112
⅛	166.8975	2216.6074	⅜	183.3909	2676.3609
¼	167.2902	2227.0507	½	183.7836	2687.8351
⅜	167.6829	2237.5187	⅝	184.1763	2699.3338
½	168.0756	2248.0111	¾	184.5690	2710.8571
⅝	168.4683	2258.5281	⅞	184.9617	2722.4050
¾	168.8610	2269.0696	59	185.3544	2733.9774
⅞	169.2537	2279.6357	⅛	185.7471	2745.5743
54	169.6464	2290.2264	¼	186.1398	2757.1957
⅛	170.0391	2300.8415	⅜	186.5325	2768.8418
¼	170.4318	2311.4812	½	186.9252	2780.5123
⅜	170.8245	2322.1455	⅝	187.3179	2792.2074
½	171.2172	2332.8343	¾	187.7106	2803.9270
⅝	171.6099	2343.5477	⅞	188.1033	2815.6712
¾	172.0026	2354.2855	60	188.4960	2827.4400
⅞	172.3593	2365.0480	⅛	188.8887	2839.2332
55	172.7880	2375.8350	¼	189.2814	2851.0510
⅛	173.1807	2386.6465	⅜	189.6741	2862.8934
¼	173.5734	2397.4825	½	190.0668	2874.7603
⅜	173.9661	2408.3432	⅝	190.4595	2886.6517
½	174.3588	2419.2283	¾	190.8522	2898.5677
⅝	174.7515	2430.1833	⅞	191.2419	2910.5083
¾	175.1442	2441.0772	61	191.6376	2922.4734
⅞	175.5369	2452.0310	⅛	192.0303	2934.4630
56	175.9296	2463.0144	¼	192.4230	2946.4771
⅛	176.3323	2474.0222	⅜	192.8157	2958.5139
¼	176.7150	2485.3546	½	193.2084	2970.5791
⅜	177.1077	2496.1116	⅝	193.6011	2982.6669
½	177.5004	2507.1931	¾	193.9931	2994.7792
⅝	177.8931	2518.2992	⅞	194.3865	3006.9161
¾	178.2858	2529.4297	62	194.7792	3019.0776
⅞	178.6785	2543.5849	⅛	195.1719	3031.2635
57	179.0712	2551.7646	¼	195.5646	3043.4740
⅛	179.4639	2562.9688	⅜	195.9573	3055.7091
¼	179.8566	2574.1975	½	196.3500	3067.9687

TABLE—(*Continued*)

ONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅝	196.7427	3080.2529	⅞	213.2361	3618.3300
¾	197.1354	3092.5615	68	213.6288	3631.6896
⅞	197.5281	3104.8948	⅛	214.0215	3645.0536
63	197.9208	3117.2526	¼	214.4142	3658.4402
⅛	198.3135	3129.6349	⅜	214.8069	3671.8554
¼	198.7062	3142.0417	½	215.1996	3685.2931
⅜	199.0989	3154 4732	⅝	215.5923	3698.7554
½	199.4916	3166.9291	¾	215.9850	3712.2421
⅝	199.8843	3179.4096	⅞	216.3777	3725.7535
¾	200.2770	3191.9146	69	216.7704	3739.2894
⅞	200.6697	3204.4442	⅛	217.1631	3752.8498
64	201.0624	3216.9984	¼	217.5558	3766.4327
⅛	201.4551	3229.5770	⅜	217.9485	3780.0443
¼	201.8478	3242.1782	½	218.3412	3793.6783
⅜	202.2405	3254.8080	⅝	218.7339	3807.3369
½	202.6332	3267.4603	¾	219.1266	3821.0200
⅝	203.0259	3280.1372	⅞	219.5193	3834.7277
¾	203.4186	3292.8385	70	219.9120	3848.4600
⅞	203.8113	3305.5645	⅛	220.3047	3862.2167
65	204.2040	3318.3151	¼	220.6974	3875.9960
⅛	204.5917	3331.0900	⅜	221.0901	3889.8039
¼	204.9894	3343.8875	½	221.4828	3903.6343
⅜	205.3821	3356.7137	⅝	221.8755	3917.4893
½	205.7748	3369.5623	¾	222.2682	3931.3687
⅝	206.1675	3382.4355	⅞	222.6609	3945.2728
¾	206.5602	3395.3332	71	223.0536	3959.2014
⅞	206.9529	3408.2555	⅛	223.4463	3973.1545
66	207.3456	3421.2024	¼	223.8390	3987.1301
⅛	207.7383	3434.1737	⅜	224.2317	4001.1344
¼	208.1310	3447.1676	½	224.6244	4015.1611
⅜	208.5237	3468.1901	⅝	225.0171	4029.2124
½	208.9164	3473.2351	¾	225.4098	4043.2882
⅝	209.3091	3486.3047	⅞	225.8025	4057.3886
¾	209.7018	3499.3987	72	226.1952	4071.5136
⅞	210.0945	3512.5174	⅛	226.5879	4085.6631
67	210.4872	3525.6606	¼	226.9806	4099.8350
⅛	210.8799	3538.8283	⅜	227.3733	4114.0356
¼	211.2726	3552.0185	½	227.7660	4128.2587
⅜	211.6653	3565.2374	⅝	228.1587	4142.5064
½	212.0580	3578.4787	¾	228.5514	4156.7785
⅝	212.4507	3591.7446	⅞	228.9441	4171.0753
¾	212.8434	3605.0350	73	229.3368	4185.3966

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅛	229.7295	4199.7424	⅜	246.2229	4824.4299
¼	230.1222	4214.1107	½	246.6156	4839.8311
⅜	230.5149	4228.5077	⅝	247.0083	4855.2568
½	230.9076	4242.9271	¾	247.4010	4870.7071
⅝	231.3003	4257.3711	⅞	247.7937	4886.1820
¾	231.6930	4271.8396	79	248.1864	4901.6814
⅞	232.0857	4286.3327	⅛	248.5791	4917.2053
74	232.4784	4300.8504	¼	248.9718	4932.7517
⅛	232.8711	4315.3926	⅜	249.3645	4948.3268
¼	233.2638	4329.9572	½	249.7572	4963.9243
⅜	233.6565	4344.5505	⅝	250.1499	4979.5456
½	234.0492	4359.1663	¾	250.5426	4995.1930
⅝	234.4419	4373.8067	⅞	250.9353	5010.8642
¾	234.8346	4388.4715	80	251.3280	5026.5600
⅞	235.2273	4403.1610	⅛	251.7207	5042.2803
75	235.6200	4417.8750	¼	252.1134	5058.0230
⅛	236.0127	4432.6135	⅜	252.5061	5073.7944
¼	236.4054	4447.3745	½	252.8988	5089.5883
⅜	236.7981	4462.1642	⅝	253.2915	5106.4060
½	237.1908	4476.9763	¾	253.6842	5121.2497
⅝	237.5835	4491.8130	⅞	254.0769	5137.1173
¾	237.9762	4506.6742	81	254.4696	5153.0094
⅞	238.3689	4521.5600	⅛	254.8623	5168.9260
76	238.7616	4536.4704	¼	255.2550	5184.8651
⅛	239.1543	4551.4023	⅜	255.6477	5200.8329
¼	239.5470	4566.3626	½	256.0404	5216.8231
⅜	239.9397	4581.3486	⅝	256.4331	5232.8371
½	240.3324	4596.3571	¾	256.8258	5248.8772
⅝	240.7251	4611.3902	⅞	257.2105	5264.9411
¾	241.1178	4626.4477	82	257.6112	5281.0296
⅞	241.5105	4641.3299	⅛	258.0039	5297.1426
77	241.9032	4656.6366	¼	258.3966	5313.2780
⅛	242.2959	4671.7678	⅜	258.7893	5329.4421
¼	242.6886	4686.9215	½	259.1820	5345.6287
⅜	243.0813	4702.1039	⅝	259.5747	5361.8391
½	243.4740	4717.3087	¾	259.9674	5378.0755
⅝	243.8667	4732.5381	⅞	260.3601	5394.3358
¾	244.2594	4747.7920	83	260.7528	5410.6206
⅞	244.6521	4763.0705	⅛	261.1455	5426.9299
78	245.0448	4778.3736	¼	261.5382	5443.2617
⅛	245.4375	4793.7012	⅜	261.9309	5459.6222
¼	245.8302	4809.0512	½	262.3236	5476.0051

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅝	262.7163	5492.4118	⅞	279.2097	6203.6905
¾	263.1090	5508.8446	89	279.6024	6221.1534
⅞	263.5017	5525.3012	⅛	279.9951	6238.6408
84	263.8944	5541.7824	¼	280.3878	6256.1507
⅛	264.2871	5558.2881	⅜	280.7805	6273.6893
¼	264.6798	5574.8162	½	281.1732	6291.2503
⅜	265.0725	5591.3730	⅝	281.5659	6308.8351
½	265.4652	5607.9523	¾	281.9586	6326.4460
⅝	265.8579	5624.5554	⅞	282.3513	6344.0807
¾	266.2506	5641.1845	90	282.7440	6361.7400
⅞	266.6433	5657.8357	⅛	283.1367	6379.4238
85	267.0360	5674.5150	¼	283.5294	6397.1300
⅛	267.4287	5691.2170	⅜	283.9221	6414.8649
¼	267.8214	5707.9415	½	284.3148	6432.6223
⅜	268.2141	5724.6947	⅝	284.7075	6450.4039
½	268.6068	5741.4703	¾	285.1002	6468.2107
⅝	268.9997	5758.2697	⅞	285.4929	6486.0418
¾	269.3922	5775.0952	91	285.8856	6503.8974
⅞	269.7849	5791.9445	⅛	286.2783	6521.7772
86	270.1776	5808.8184	¼	286.6710	6539.6801
⅛	270.5703	5825.7168	⅜	287.0637	6557.6114
¼	270.9630	5842.6376	½	287.4564	6573.5651
⅜	271.3557	5859.5871	⅝	287.8491	6593.5431
½	271.7484	5876.5591	¾	288.2418	6611.5462
⅝	272.1411	5893.5549	⅞	288.6345	6629.5736
¾	272.5338	5910.5767	92	289.0272	6647.6258
⅞	272.9265	5927.6224	⅛	289.4199	6665.7021
87	273.3192	5944.6926	¼	289.8125	6683.8010
⅛	273.7119	5961.7873	⅜	290.2053	6701.9286
¼	274.1046	5978.9045	½	290.5980	6720.0787
⅜	274.4973	5996.0504	⅝	290.9907	6738.2530
½	274.8900	6013.2187	¾	291.3834	6756.4525
⅝	275.2827	6030.4108	⅞	291.7661	6774.6763
¾	275.6754	6047.6290	93	292.1688	6792.9248
⅞	276.0681	6064.8710	⅛	292.5615	6811.1974
88	276.4608	6082.1376	¼	292.9542	6829.4927
⅛	276.8535	6099.4287	⅜	293.3469	6847.8167
¼	277.2462	6116.7422	½	293.7396	6866.1631
⅜	277.6389	6134.0844	⅝	294.1323	6884.5338
½	278.0316	6151.4491	¾	294.5350	6902.9296
⅝	278.4243	6169.8376	⅞	294.9177	6921.3497
¾	278.8170	6186.2591	94	295.3104	6939.7946

TABLE—(Concluded)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅛	295.7031	6958.2636	⅛	305.1279	7408.8868
¼	296.0958	6976.7552	¼	305.5206	7427.9675
⅜	296.4885	6995.2755	⅜	305.9133	7447.0769
½	296.8812	7013.8183	½	306.3060	7466.2087
⅝	297.2739	7032.3853	⅝	306.6987	7485.3648
¾	297.6666	7050.9775	¾	307.0914	7504.5460
⅞	298.0593	7069.5940	⅞	307.4841	7523.7515
95	298.4520	7088.2352	98	307.8768	7542.9818
⅛	298.8447	7106.9005	⅛	308.2695	7562.2362
¼	299.2374	7125.5885	¼	308.6622	7581.5132
⅜	299.6301	7144.3052	⅜	309.0549	7600.8189
½	300.0228	7163.0443	½	309.4476	7620.1471
⅝	300.4155	7181.8077	⅝	309.8403	7639.4995
¾	300.8082	7200.5962	¾	310.2330	7658.8771
⅞	301.2009	7219.4090	⅞	310.6257	7678.2790
96	301.5936	7238.2466	99	311.0184	7697.7056
⅛	301.9863	7257.1083	⅛	311.4111	7717.1563
¼	302.3790	7275.9926	¼	311.8038	7736.6297
⅜	302.7717	7294.9056	⅜	312.1965	7756.1318
½	303.1644	7313.8411	½	312.5892	7775.6563
⅝	303.5571	7332.8008	⅝	312.9819	7795.2051
¾	303.9498	7351.7857	¾	313.3746	7814.7790
⅞	304.3425	7370.7949	⅞	313.7673	7834.3772
97	304.7352	7389.8288	100	314.1600	7854.0000

For circumference of circles larger than those given in th table, multiply the diameter by 3,1416.

Example.—Diameter 101″ × 3,1416 = 317,3016.

For areas larger than those in the table, multiply the squa of the diameter by the decimal .7854.

Example.—101 inches × 101 = 10201 × .7854 = 8011,86 sq. in

Weights and Measures.

ıere have been innumerable systems of weights and measures, country, until recently, having its own system. In fact, in ıer years different provinces of the same country often used ly differing systems. Of late years, however, the tendency has toward the adoption of a common decimal system,—that is, a m in which one unit contains ten of the units of the next smaller mination. The metric system, which is a decimal system, based he *meter*, a certain fixed unit of length, and the *gram*, the ht of a fixed volume of water at a certain fixed temperature, been adopted by many of the European and American coun-. Great Britain and the United States, however, still retain old system of weights and measures, but it is to be hoped the much simpler metric system will be adopted in time. The wing tables contain the units in both systems and their valents.

American System.

MEASURES OF LENGTH.

lle.	Furlongs.	Chains.	Rods.	Yards.	Feet.	Inches.
1	8	80	320	1760	5280	63360
	1	10	40	220	660	7920
5	0.1	1	4	22	66	792
125	0.025	0.25	1	5.5	16.5	198
6818	0.0045454	0.45454	0.181818	1	3	36
18939	0.00151515	0.01515151	0.0606060	0.33333	1	12
15783	0.000126262	0.001262626	0.00505050	0.00277777	0.083333	1

MEASURES OF SURFACE.

Mile.	Acres.	S. Chains.	Sq. Rods.	Sq. Yards.	Sq. Feet.	Sq. Inches.
1	640	6400	102400	3097600	27878400	4014489600
62	1	10	160	4840	43560	6272640
562	0.1	1	16	484	4356	627264
09764	0.00625	0.0625	1	30.25	272.25	39204
00323	0.0002066	0.002066	0.0330	1	9	1296
000358	0.00002296	0.0002296	0.00367	0.1111111	1	144
0000025	*0.000000159*	*0.00000159*	0.00002552	20.0007716	0.00694A	1

MEASURES OF CAPACITY.

DRY MEASURE.

Cub. Yard.	Bushels.	Cub. Feet.	Pecks.	Gallons.	Cub. Inch.
1	21.6962	27	100.987	201.974	46656
0.03961	1	1.24445	4	9.30918	2150.42
0.037037	0.803564	1	3.21425	7.4805	1728
0.009259	0.25	0.31114	1	2.32729	537.605
——	0.107421	0.133681	0.429684	1	231
——	——	0.000547	0.001860	0.004329	1

LIQUID MEASURE.

Gallon.	Quarts.	Pints.	Gills.	Cub. Inch.
1	4	8	32	221
0.25	1	2	8	57.75
0.125	0.5	1	4	28.875
0.03125	0.125	0.25	1	7.21875
0.004329	0.017315	0.03463	0.13858	1

MEASURES OF WEIGHTS.

AVOIRDUPOIS.

Ton.	Cwt.	Pounds.	Ounces.	Drams.
1	20	2240	35840	573440
0.05	1	112	1792	28672
0.00044642	0.0089285	1	16	256
0.00002790	0.000558	0.0625	1	16
0.00000174	0.0000348	0.0016	0.0625	1

TROY.

Pounds.	Ounces.	Dwt.	Grains.	Pound Avoir.
1	12	240	5760	0.822861
0.083333	1	20	480	0.068571
0.004166	0.05000	1	24	0.0034285
0.0001736	0.002083333	0.0416666	1	0.00014285
1.215275	14.58333	291.6666	7000	1

APOTHECARIES.

Pound.	Ounces.	Drams.	Scruples.	Grains.
1	12	96	288	5760
0.08333	1	8	24	480
0.01041666	0.125	1	3	60
0.0034722	0.0416666	0.3333	1	20
0.00017361	0.0020833	0.016666	0.05	1

Metric System.

MEASURES OF LENGTH.

illimeters (mm.)	= 1 *centimeter*,	cm., =	.3937 inch.
ntimeters,	1 decimeter,	dcm.,	3.937 inches.
cimeters,	1 METER,	me.,	39.37 inches.
eters,	1 dekameter,	dkm.,	393.7 inches.
kameters,	1 hectometer,	hm.,	328 ft. 1 in.
ctometers,	1 *kilometer*,	km.,	3280 ft. 10 in.
ilometers,	1 myriameter,	mym.,	6.2137 miles.

MEASURES OF SURFACE.

millimeters (mm^2.)	= 1 *sq. centimeter*,	cm^2., =	.00155 sq. in.
centimeters,	1 sq. decimeter,	dcm^2.,	.1076 sq. ft.
decimeters,	1 SQ. METER,	m^2.,	11.96 sq. yd.

Also,

tiares (ca.), or sq. me.,	= 1 ARE,	ar., =	119.6 sq. yd.
s,	1 *hectare*	ha.,	2.471 acres.

MEASURES OF CAPACITY.

u. millimeters (mm^3.),	1 *cu. centimeter*,	cm^3., =	.061 cu. in.
u. centimeters,	1 cu. decimeter,	dcm^3.,	61.022 cu. in.
u. decimeters,	1 CU. METER,	m^3.,	1.308 cu. yd.

Also,

isteres (dcs.)	= 1 STERE, or cu. meter,	st., =	1.308 cu. yd.
es,	1 dĕkastere,	dks.,	13.08 cu. yd.

And

LIQUID MEASURE.

illiliters (ml.)	= 1 *centiliter*,	cl., =	.338 fluid oz.
ntiliters,	1 deciliter,	dcl.,	.845 liq. gill.
ciliters,	1 LITER,	lt.,	1.0567 liq. qt.
ers,	1 dekaliter,	dkl.,	2.6417 liq. gal.
kaliters,	1 *hectoliter*,	hl.,	2 bu. 3.35 pk.
ctoliters,	1 kiloliter,	kl.,	1.308 cu. yd.

MEASURES OF WEIGHT.

10 *milligrams* (mg.)	= 1 centigram,	cg.,	= .1543 grain.
10 centigrams,	1 decigram,	dcg.,	1.543 grains.
10 decigrams,	1 Gram,	gm.,	15.432 grains.
10 grams,	1 dekagram,	dkg.,	.3527 av. oz.
10 dekagrams,	1 hectogram,	hg.,	3.5274 av. oz.
10 hectograms,	1 *kilogram*,	k.,	2.2046 av. lb.
10 kilograms,	1 myriagram,	myg.,	22.046 av. lb.
10 myriagrams,	1 quintal,	q.,	220.46 av. lb.
10 quintals,	1 *tonneau*,	t.,	2204.6 av. lb.

COMPARATIVE TABLE OF THE ENGLISH (AMERICAN) AND METRIC SYSTEMS.

An inch	= 2.54 centimeters.	A gallon	= 3.786 liters.
A foot	= 30.48 centimeters.	A bushel	= 3524 hectolite
A mile	= 1.6094 kilometers.	A cu. inch	= .01639 liter.
A sq. inch	= .0006452 sq. meter.	A cu. yard	= .7646 stere.
A sq. foot	= .0929 sq. meter.	A cord	= 3.625 stere.
A sq. yd.	= .8362 sq. meter.	A grain	= .0648 gram.
A sq. rod	= .2529 are.	A Troy lb.	= .373 kilo.
An acre	= .4047 hectares.	An av. lb.	= .4536 kilo.
A sq. mile	= 259 hectares.	A com. ton	= .9071 tonneau.

MISCELLANEOUS MEASURES.

1 cord = 4 ft. × 4 ft. × 8 ft. = 128 cubic feet.
1 knot or nautical mile = 6080.26 feet.
1 gallon (U. S.) = 231 cubic inches.
1 barrel = 31½ gallons,
1 hogshead = 63 "
1 pound avoirdupois = 7000 grains.
1 " troy = 5760 "
1 " apothecaries = 5760 "
1 board foot = 12 in. × 12 in. × 1 in. thick—i. e

in board measure, boards are assumed to be one inch thick. Henc *to find the* board feet in any piece of timber, multiply length i *feet by* breadth in feet by thickness in inches.

QUESTIONS.

What does the sign + mean?
What is the sign of a proportion?
What is the Roman notation corresponding to 27?
What does 4 : 2 mean? What is it equal to?
What is the rule of three?
What is the sixth power of 5?
What is the cube root of 125?
What is the square of 10.1?
What is the square root of 198 from the tables?
Find the value of x in the equation $10x + 9 = 4x + 21$.
What is the logarithm of 74.6?
Divide, using logarithms, 64.2 by 2.34.
What is the 10th power of 1.2?
What is the square root of 8.64?
What is a regular polygon?
What is a hexagon?
Define a circle.
Define a sphere.
How would you calculate the area of any parallelogram?
How find the area of a circle?
How find the cubical contents of a cylinder?
How obtain the volume of a sphere?
What is a spheroid? How obtain its volume?
How obtain the area of an ellipse?
Give rule for obtaining the volume of a pyramid.
How obtain the contents of the frustum of a cone?
How would you obtain the cubic contents of an irregular piece stone?
How could you obtain the number of gallons contained in a sk?
What is the relation between a pound Troy, a pound avoirdu- is, and a pound apothecaries weight?
What is the relation between a foot and a centimetre?
How many litres are equivalent to 10 gallons?

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